THE
WONDERS OF
LIGHT

BY

W. E. FLOOD

LONGMANS

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Turning night into day: lights in the 'skyscrapers' of New York after the December sun has set.

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W. E. FLOOD, M.A.

Lecturer in Education, University of Birmingham

*With Diagrams
and Photographs*

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CONTENTS

CHAPTER I

FIRST IDEAS

SUPPOSE, one dark night, you go into a room in which there is no lamp. Can you find out what things there are in the room ? Some things, such as the table, you can feel ; others, such as a jar of flowers, you can smell. You might recognise some things by tasting them, and there may be some things which make a noise so that you can hear them. How much more you could find out if you had a lamp ! Then you could SEE. We learn more about the world around us by seeing than in any other way. We see the buildings in the town, the animals in the field ; we see the trees, the clouds, the hills, and the rivers. We see our friends ; we see the words and pictures in this book. We depend upon our power to see in nearly everything we do.

We cannot see, of course, if there is no LIGHT. By day the sun sends us light ; at night we use lamps of various kinds. Anything which makes and sends out light is called a " source " of light. Let us make a list of the well-known sources of light. We have already noted that the sun and lamps are sources. Then we think of a candle, of a piece of burning wood or paper, and then of a fire itself. All of these sources, of course, make light, but they are also alike in another way. They are all hot. We know that the sun is hot because, although it is very far away, we can feel its heat on our bodies. The flame of a candle, or of an oil-lamp, or of a piece of burning paper is hot. The fire is hot. If you touch the glass of a large electric lamp you find that it is hot. You cannot

always feel the heat of a small electric lamp, but, as we shall read later, the wire inside an electric lamp, large or small, is very hot. It seems, then, that every source of light is hot. This is very nearly true. Sources of light which are not hot are very uncommon.

Although all ordinary sources of light are hot, we must not think that all hot things are sources of light. Hold an iron rod with one end in a fire for a minute or two. It becomes hot. If now you hold it near your body, you can feel that it sends out heat. It is not a source of light. If you take it into a dark room, you cannot see it or other things in the room. If, however, you hold the rod in the fire for a longer time, it becomes hotter and red in colour. We say that it is " red-hot." It sends out heat. If you take it into a dark room, you find that it is also a source of red light. If it is made very hot (hotter than an ordinary fire) it sends out a very bright light. We learn, then, that hot things send out heat, and very hot things send out both heat and light.

Light travels from the sun to the Earth ; light travels from a lamp to the walls of a room. How fast does light travel ? If we bring a lamp into a room, we immediately see the walls and the various things in the room. The light must travel to them very, very quickly. If a man turns on the lamp of his car, its light reaches the other end of the street almost immediately. Light travels so fast that scientists have only measured its speed with great difficulty. The speed is 186,000 miles PER SECOND ! A very fast aeroplane can fly at a speed of 600 miles an hour, that is $\frac{1}{6}$ mile per second. If an aeroplane could fly at 600 miles an hour right round the Earth, it would take rather more than 40 hours for the journey. Light could travel seven times round the Earth in one second !

The light which travels out from a source may fall on substances like glass through which it can pass, or on substances like stone through which it cannot pass. The light from the sun, for example, may fall on a house. It passes through the glass windows but not through the walls. Substances through which light can pass are said to be " transparent." Glass is transparent, a thin layer of water is transparent, and of course air is transparent. Those substances through which light cannot pass are said to be " opaque." Wood, metals, and stone are opaque substances. Transparent substances are far less common than opaque substances.
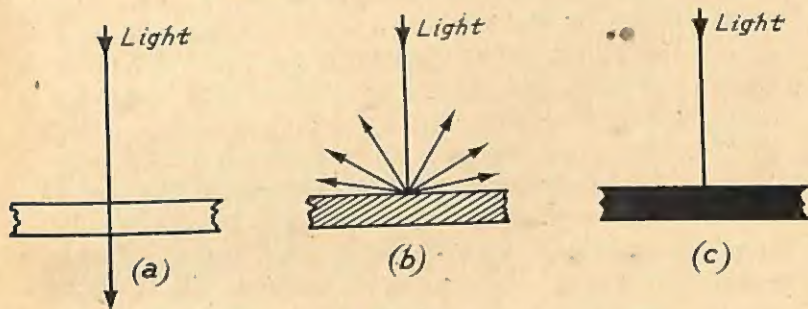

FIG. 1.

We may ask what happens to the light which falls on an opaque substance. It cannot pass through. Two things may happen to the light. Some of it may be thrown off again, usually in all directions, but some of it may be taken in and lost. Fig. 1a represents light passing through a transparent substance. In Fig. 1b the light strikes an opaque substance. Some of the light is thrown off again in all directions ; some (which, of course, the drawing cannot show) is taken in. Some substances throw off most of the light which falls on them. You know how

brightly a piece of clean metal shines in the sunshine. The metal throws off most of the light which falls on it. An object which is perfectly black takes in all the light which falls on it and throws off none (Fig. 1c).

We can now better understand why we see things. We see things because light comes from them to our eyes. The sunlight falls on a tree. The tree throws off some of the light again. Light from the tree comes to our eyes. We see the tree. We use a lamp in a room at night. Light from the lamp falls on things in the room and then comes from the things to our eyes. We see them. It is most important to learn that nothing goes out from our eyes. We see when light comes *from* things *to* our eyes. Actually we do not see black things because no light comes from them. You do not really see the black printing in this book, but you see the white paper round the letters and so know their shapes.

It is quite clear now why we cannot see things in the dark. If no light falls on objects, they cannot throw off light to our eyes. A teacher once asked a boy, " Would a thief be foolish if, on a perfectly dark night, he wore white clothes ? " The answer, of course, is No ! If the night were really dark, there would be no light at all, and no one could see the thief whatever clothes he wore. It is rare, however, for a night to be completely dark. People sometimes say that cats and certain other animals can see in the dark. These animals cannot see in the dark. They can see, however, when there is only very little light.

If you look back over these first few pages, you will notice that we have always spoken of seeing *things*. We have not said that we can see *light*. Can we see light ? We stand a lamp in the middle of the room. Light travels from the lamp to the various things in the room, and from these things to our eyes. Can we see the *light* which

travels ? No, we cannot see it. Light travels from the sun to a tree, for example, and then some of it travels from the tree to our eyes. We see the tree, but we do not see the light. But surely, you may say, we can see the light which streams out from an electric torch, or from the lamp of a car, especially if the air is misty. Again, you may say, we can see the sunlight which streams through a hole or crack in a door into a dusty room. Let us describe an experiment which will help us to find an answer to our problem.

We use a glass tank (or box) which is about a foot long and about 6 inches wide and tall. We cover the bottom of the tank, inside, with grease. We shall cover the open top of the tank with a wooden board. Before we do this, we rub some chalk on one side of the board. We place the board over the top with this side downwards. We then leave the tank for a day or two in a place where no one will disturb it. During this time the dust in the air in the tank gradually falls to the bottom and sticks in the grease. (Most of the chalk hangs to the board.) The tank then contains air which is free from dust.

Now we come to the main part of the experiment. We need a lamp which gives a fairly narrow stream of light and does not send light in all directions. A bicycle lamp or a lantern (page 80) is suitable. We call a fairly narrow stream of light a " beam." Fig. 2 shows how we arrange the apparatus. The lamp sends a beam of light through the tank. We turn off all other lamps in the room, and then stand at the side of the apparatus. Can we see the beam of light ? We think, perhaps, we can see the beam before it reaches the tank and after it comes out on the other side. If we shake some dust, or blow some smoke, into these parts of the beam we can see its path quite clearly. We cannot, however, see the beam as it passes
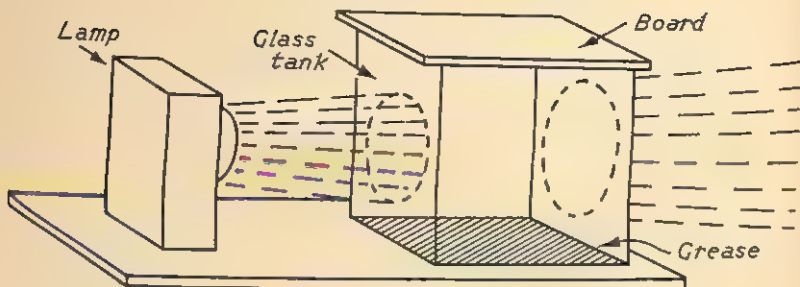
Fig. 2.

through the tank. The inside of the tank is dark; the beam seems to stop when it reaches the tank, and to start again when it comes out on the other side.

What can we learn from this experiment so far? *We cannot see a beam of light which passes through air in which there is no dust.* We think we can see a beam of light

(G. A. Clarke.)

Sun shining from behind clouds. Dust enables us to see the beams.

which passes through dusty air. But, even then, do we really see the beam of light, or do we only see the particles (very small bits) of dust on which the light falls ? We tap the board on the top of the tank. Particles of chalk dust fall from the board. We see them as they fall through the beam. They show us where the beam is, but it is the chalk, not the beam, which we see. We learn, then, that when we think we see a beam of light we really only see the particles of dust (or of smoke, or of mist) on which the light falls. *We do not see the beam of light itself.*

It is much easier to say " Look at that beam of light " than to say " Look at those particles of dust which are lit up by that beam of light." So quite often we speak of seeing a beam of light, indeed we shall sometimes do so in this book.

TURNING NIGHT INTO DAY

THE sun is our chief source of light but it only shines during the day. At night the moon and the stars may shine. Their light, however, is weak. Men have invented their own sources of light for use during the hours of darkness. We want good lamps in our homes so that we can work, read, or amuse ourselves before going to bed. We want the streets in our towns to be well lit so that we can see where to walk. Cars, trains, ships, and aeroplanes carry lamps so that they can travel with safety. Doctors in hospitals need good lamps so that, at any hour of the night, they can do their work of helping sick or injured people. Big factories in England do not close at night. Some men work during the day; others work during the night. The factories must be lit by lamps during the night. By means of lamps men try to "turn night into day" for the convenience, safety, and pleasure of us all.

The first source of light which Man made was undoubtedly a fire. The fire gave him heat and also a little light. Then, perhaps, he found that he could make a better source of light by using just one burning stick. He could tie it to the wall of his "room" (probably a cave) and as it burned it sent out light. Next, perhaps, he found that those kinds of wood which contain oil burned most brightly and that any kind of wood would burn brightly if he covered it with fat from animals killed in the hunt. He now had a kind of burning torch which he could carry about. The fat which is obtained, by heating, from the

flesh of animals is called "tallow." The time came, certainly thousands of years ago, when it was realised that there was no need to put the tallow on a stick. It could be put in a clay or stone cup (or the bone of an animal's head !) and burned there. So Man made his first lamp. We use the same idea to-day when we light a candle.

In the middle of a candle there is a piece of material something like string. We call it the "wick." (There is a wick, of a slightly different kind, in an oil-lamp.) What is the purpose of the wick ? If you hold a narrow glass tube with its lower end in a jar of water, some water rises part way up the tube (Fig. 3). The water rises higher in a narrow tube than in a wide one. Now a tallow lamp, as described above, burned up too much tallow at once and was very smoky. A wick consists of a number of threads of cotton and *the spaces between the threads form very narrow tubes*. As a candle burns, the heat melts the fat or wax of which it is made, and just enough of the fat or wax rises up the wick for the burning to be steady.
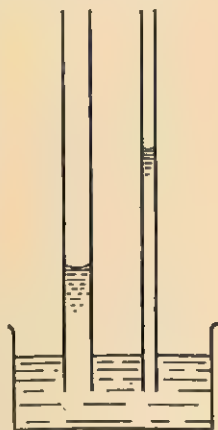

FIG. 3.

The first candles were made of tallow. They were rather smoky and made an unpleasant smell as they burned. Candles are usually made now of a mixture of two substances called "stearin" and "paraffin wax." Stearin is a pure kind of fat made from tallow, but which burns without making an unpleasant smell. Paraffin wax, like kerosene and many other oils, is made from an oil (called "petroleum") found in the ground in some parts of the world.

Another source of light which was invented hundreds of years ago is the oil lamp. At first " vegetable oils " were used, and, in some districts, are still used. These oils are obtained by pressing the nuts and fruits of certain trees. (Palm oil, for example, is obtained from the fruit of some kinds of palm trees.) Vegetable oils do not rise up a wick very well. In the middle of the last century, kerosene (or paraffin) was discovered. We call it a " mineral oil " because petroleum, from which it is made, is obtained from rocks. A mineral oil rises better in a wick than a vegetable oil and burns with a brighter flame.

If you have an oil lamp in your home, examine it carefully. Look at the wick. What is it made of ? How is it raised to a convenient height ? If the oil is to burn well, it must have a good supply of air. How does fresh air reach the flame ? Often there are holes near the bottom of the lamp. The air inside the glass chimney is heated by the flame and becomes lighter than the air outside. The air outside pushes in through the holes and drives the hot air (and smoke) out. In this way the oil always has a good supply of fresh air.

Candles and oil lamps were Man's chief sources of light at night for hundreds of years. The streets of Paris (France) were first lit by oil lamps in 1765 and those of London 20 years later. Although oil lamps, of a much better kind, are still used to light many houses and buildings, lamps of a new kind have taken their place in most parts of the world. These are electric lamps.

In an ordinary electric lamp the current flows through a very thin piece of wire called the " filament." A very thin wire opposes or resists the flow of electricity through it. When we drive a current through the wire it becomes very hot. The filament of an ordinary electric lamp

becomes nearly white-hot almost immediately we turn on the current, and then sends out much light as well as heat.

Two scientists, Swan in England and Edison in America, experimented with this idea about 70 years ago. The first difficulty was to find a suitable substance from which to make the filament. Ordinary metals could not be used because they would melt with the heat. At first the rare metal platinum was tried, but the black substance carbon [1] (which is not a metal) was found to be more suitable. As you can well imagine great skill was needed to make the very thin filaments from carbon. Then there was another difficulty. Carbon burns when it is heated in air. If a carbon filament hangs in air it will burn away very quickly. The problem was solved by hanging the filament inside a glass vessel, pumping the air out through a hole, and then closing the hole so that air could not get back. The carbon filament could not burn because it had no air. This filament could only be heated enough to make it give out orange light, and to-day we think carbon filament lamps are poor ones.

The filament of an electric lamp is now made of a metal called tungsten. Fifty years ago only a few people had ever heard of tungsten. It is a very hard metal and (of particular importance to us here) it does not easily melt. A tungsten filament can be made white-hot. It is still necessary to put the filament in a glass vessel and to pump out the air because tungsten rusts in air when it is made hot. Usually another gas (which will not burn) is put back in place of the air.

We call the glass vessel with the filament inside a " bulb." Fig. 4a is a drawing of a common kind of bulb. The filament is supported from a glass strip in the middle. It

[1] Coal and half-burnt (black) wood consist largely of carbon.

may be star-shaped, as shown in the drawing, but it is best
made in the shape of a spring or coil. There is a little
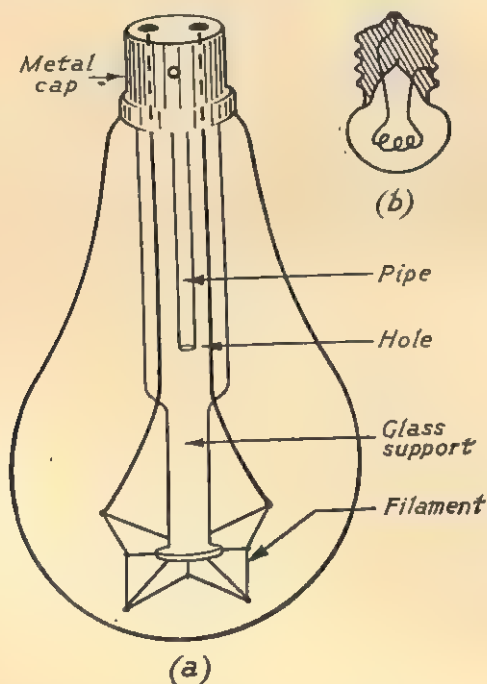pipe inside the glass strip. The air was pumped out through

Fig. 4.

this pipe and the other gas put in. Then the top of the
bulb was closed and the metal " cap " put on. The ends
of the filament are joined to two thicker wires inside the
glass strip and these are joined to the two knobs on
the top of the cap. In smaller bulbs, such as we use in
electric torches and electric bicycle lamps, there is no
glass strip (Fig. 4b). The air was pumped out through

the pointed end of the bulb, which was then closed up. Often only one wire joins a knob on the top of the cap; the other wire joins to the cap itself at the side.

In order to light an electric lamp we must have a source of electricity. Torches and bicycle lamps contain a small "battery" to supply the electricity. Cars and aeroplanes carry bigger batteries, but their engines also make electricity. Factories and some large houses sometimes have machines for making their own electricity. In large towns of most countries there are very big factories called "power-stations," where electricity is made by large machines and sent to

(Fox Photos Ltd.)

A lighthouse in the sea. Its light reaches many miles and warns sailors of dangerous rocks.

buildings along thick wires which are either buried under the streets or supported on tall posts. Where is the nearest power-station to your home? How is the electricity carried from the power-station to houses and other buildings?

The brightest kinds of electric lamps, rather strangely, depend upon an idea which was discovered many years before Swan and Edison invented the lamp with a filament. Most of us have seen a very bright flash of light in the sky during a storm. We call it lightning. An English scientist called Davy found how to copy lightning, in a very small way, in his science room. Further, he could

make his "lightning" last as long as he wished. He
used two thick rods of carbon and joined them to a very
strong source of electricity (Fig. 5). First he made the
carbon rods touch and then he pulled them a short
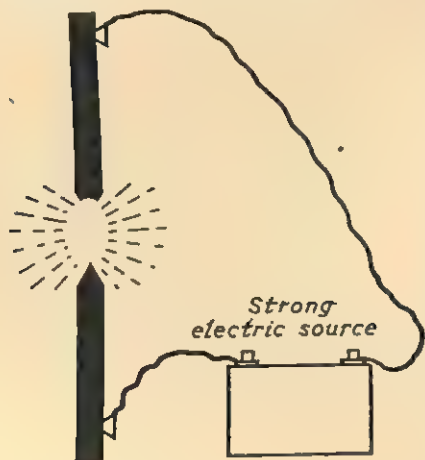distance apart. The electric current jumped through the
air between the ends
of the rods, and as it
did so it made a VERY
bright light. We now
call this kind of light an
"arc-light." The ends
of the carbon rods
slowly burn away, and
from time to time the
rods must be pushed
closer together.

Arc-lights were used
at one time to light
streets and railway
stations in a few large
towns in England; they

FIG. 5.

*Strong
electric source*

could not be used in houses because they were too bright!
We use them now when, for any special reason, we need
a very bright source of light. During the war, when
enemy aeroplanes flew over towns in England and other
countries, special lamps were used to send bright beams
of light into the sky at night so that the aeroplanes could
be seen. We call these lamps "searchlights" because,
with their help, men "search" or look for aeroplanes. A
searchlight is an arc-light. A reflector (page 45) is put be-
hind the arc-light and a *very* bright beam of light is made.
(See the picture opposite.) Arc-lights are also some-
times used to light up the outsides of famous buildings at
night on special occasions. We call it "flood-lighting."

(*Picture Post Library.*)
A searchlight. The arc-lamp is as powerful as about
200 million candles.

In the last few years a new kind of lamp has been tried.
Fig 6 shows a wide glass tube closed at each end. Inside,
near each end, there are pieces of metal (marked A and B)
and these are joined, by wires which pass through the glass,
to a strong source of electricity. Now an electric current
will not flow through the air from A and B. (This is not
like an arc-light in which the carbon rods are first made
to touch and then separated only a short distance.) If,

(By courtesy of the G.E.C.)

The new kinds of electric lamps in a London street. (You can also see the older lamps which are no longer used.)

however, most of the air is pumped out through the little tube T at the side, a small electric current flows through the little air which is left. As it does so, the air shines with a pale purple light. Other gases shine with light of different colours. These simple tubes do not shine brightly enough for us to use them as lamps, but the idea has been used in an improved way. The inside of the tube is covered with a certain powder. Then, when the current flows, the powder shines and makes a very good light.

Lamps of this kind cost more to make than ordinary electric lamps but they use less electricity. The light which they make is almost as white and bright as daylight. One day, perhaps, they will be more common than the ordinary lamp with a filament.
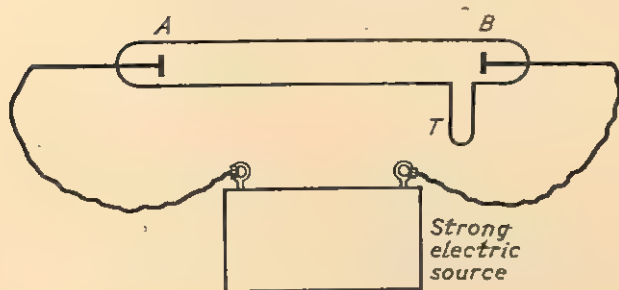
FIG. 6.

There we must end this story of lamps.   In many ways Man turns night into day for his convenience, his pleasure, and his safety.

(*The Times.*)

Buckingham Palace in London, " flood-lit " on the evening before the marriage of Princess Elizabeth.

STRAIGHT LINES AND SHADOWS

WE have noted that although we cannot really see a beam of light, dust or other particles in the air enable us to see the path of a beam of light. Thus we sometimes see the path of a beam of sunlight which comes through a hole in the door into a dusty room ; we often see the path of a beam of light from an electric torch or a car lamp at night. Whenever we " see " a beam of light we notice that the edges of the beam are straight. This is clearly shown in the picture of the searchlight on page 21. This makes us think that *light travels straight*. Even the thinnest beams which we can make have straight edges. We shall call the thinnest beam of light which we can imagine a " ray." A ray of light travels straight.

In ordinary life we have often assumed that light travels straight, even if we have not actually realised it. Thus we do not expect to be able to see round the corner of a street, or to see something which is behind a tree. We do not expect the light from a lamp to bend round the sides of an opaque object and shine into the space behind. We know that a shadow is formed.

Let us think a little more carefully about shadows. Look at Fig. 7. A piece of card (or other opaque object) is held a short distance away from a candle. Further away there is a white wooden screen. (In this book we shall use the word " screen " to mean any piece of paper, card, wood, cloth, etc., usually white, on which we throw shadows or pictures.) We see a shadow on the screen. In Fig. 7 a line has been drawn from one part of the shadow
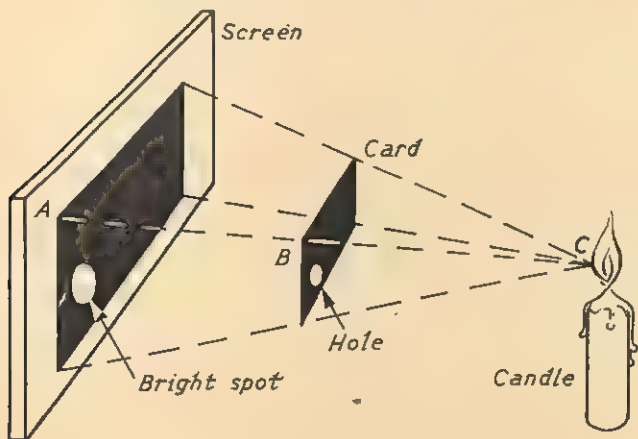
FIG. 7.

(the corner A) to the same part of the object (the corner B) and then to the candle C. It is a straight line. Whatever line is drawn in this way is a straight line. Also the candle, the hole in the card, and the bright spot on the screen are in a straight line. Now the shadow would not be like this if the light did not travel straight; in fact, the sizes and shapes of shadows prove, in a very good way, that light travels straight.

Here is an interesting piece of apparatus which you can make. You need a narrow cardboard box about a foot long (it may be square or round) and a piece of very thin paper. Fig. 8 shows what you have to make. At one end there is a small hole, made with a pin, and at the other end there is a bigger hole, about ½ inch across. The piece of paper is stuck across the middle of the box, inside, so that it is fairly flat. (You must think how best to do this when you have examined your box.) Now hold the box level with your eye, so that you can look through the

big hole, and point the box towards a bright object, such as a candle, or a window, or a tree with bright clouds behind it. You see a little picture of the object on the paper. You notice something strange about this picture. It is upside down.
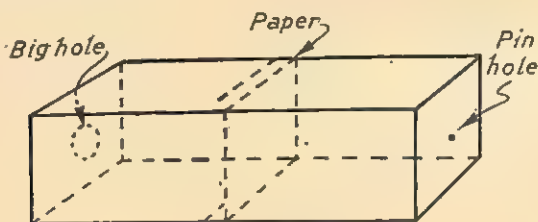

FIG. 8.

How has this picture been made? Let us try another experiment before we answer this question. Take two pieces of white cardboard and fix each to a piece of wood or cork so that you can stand them upright. Make a pin-hole in the middle of one of them. Stand this card about 5 inches from a lighted candle, and stand the other card, which is to be a screen, about 5 inches behind the first card. Turn out any lamps in the room. You see an upside down picture of the candle flame on the screen. So far, the experiment is much like the earlier one. Now make the hole a little bigger. The picture of the flame is a little bigger, but not quite so clear. Make the hole bigger still. The picture becomes less clear. When you make a big hole you cannot see a clear picture at all; instead there is one fairly bright area on the screen. Take the card with the hole right away. Now, as you know, all the screen is bright and there is no picture.

Fig. 9 helps us to understand these things which we have seen. Light spreads out in all directions from all
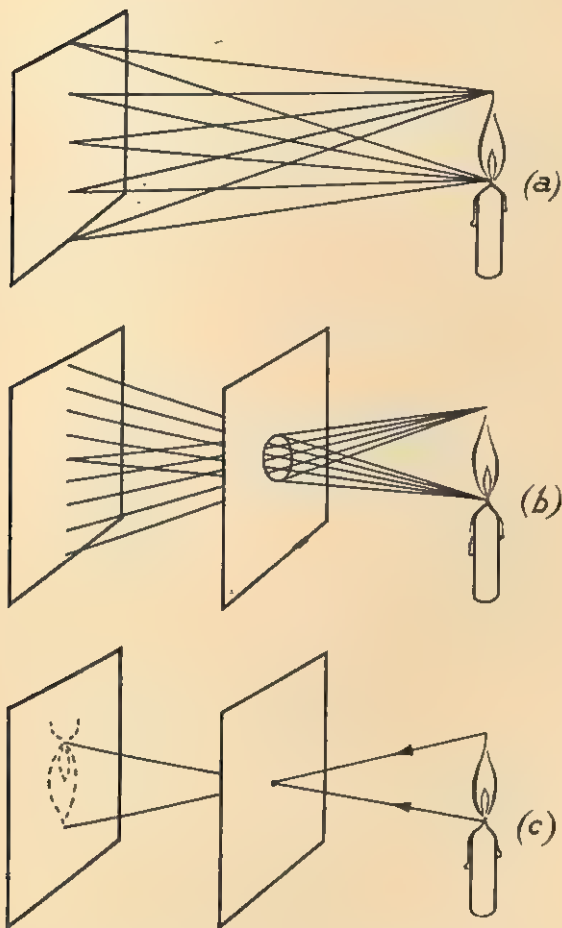
FIG. 9.

parts of the candle flame. The drawings only show rays of light which come from the top and the bottom of the flame. In the first drawing (a) there is no card in front of the screen. *Every part of the flame sends light to every part of*

the screen. The screen is bright all over. If we put a card with a very big hole between the candle and the screen, the middle part of the screen is still bright. You can make your own drawing of this. In the second drawing (b) the card has a hole of moderate size. Those rays from the top and the bottom of the flame which can get through the hole have been drawn. The middle of the screen still receives light from all parts of the candle. The top of the screen, however, only receives rays from the bottom of the flame, and the bottom of the screen only receives rays from the top of the flame. In the third drawing (c) the card has only a pin-hole. Only one ray (or very few rays close together) from each part of the flame can get through the hole. Light from the top of the flame falls on just one part of the screen (near the bottom) ; light from the bottom of the flame falls on just one part of the screen (near the top). In the same way, light from some other part of the flame, the middle for example, falls on just one part of the screen. *As each part of the flame lights up just one part of the screen* a picture is made. It is quite clear why the picture is upside down.

You notice that we have been able to explain how the picture is made because we know that light travels straight. You can now think how the picture would change if you moved the screen further away from the card with the pin-hole. When you have thought, try the experiment and see if you are right.

As we shall read later, there are many uses of a picture on a screen. Unfortunately, the picture which we have made is not very bright, but rather dim, because so little light gets through the pin-hole. If we make the hole big, to let through plenty of light, we do not make a picture. We want " something " which will make all the rays from

part of the source go°to one part of the screen.   Later we
shall learn what that " something " is.

Now we must find out a bit more about shadows.   Look
at a shadow carefully.   Hold your hand between a lamp
and a piece of paper a foot or two away.   The edges of the
shadow are not quite sharp and clear.   Hold your hand
fairly near a lamp so that it makes a shadow on a wall
some distance away.   The shadow is not very dark and it
is far from clear.   Why.are the edges of shadows seldom
clear ?   Again an experiment will help us to find the
answer.

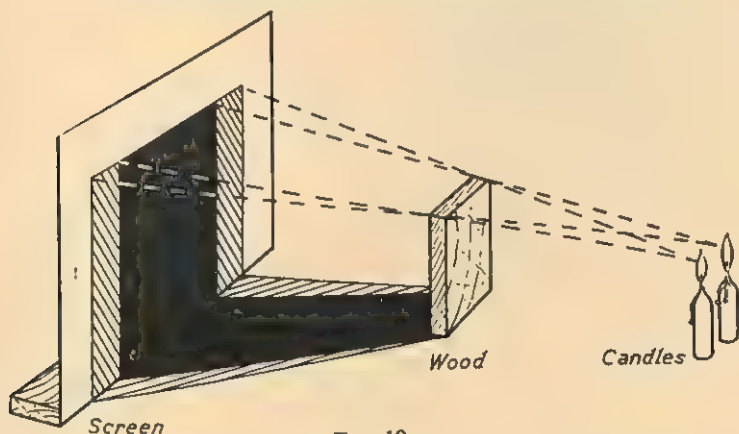We use two candles, side by side, as the source (Fig. 10).

FIG. 10.

The screen consists of thin cardboard (because later we
shall need to make holes in it) and the object to make the
shadow can be a piece of wood, a brick, or any similar
opaque object.   There must be no lamps or daylight in
the room.   The shadow on the screen consists of a large
dark part in the middle and *a less dark strip on each side*.
Make a little hole in the screen where the dark part of the

shadow comes and then look through from behind. You cannot see the candles. *No light comes to this part of the screen.* Make another little hole where the less dark edge of the shadow comes and look through from behind. You see one candle. *This part of the screen receives light from one candle only.* If you look through a hole made right outside the shadow you can see both candles.
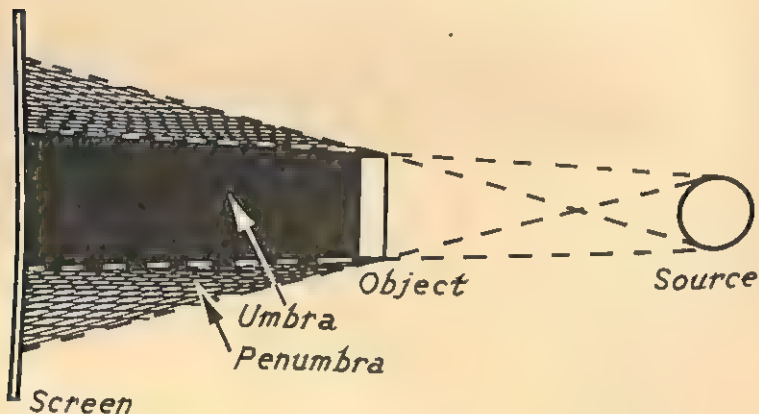

FIG. 11.

Now suppose that, instead of using two candles, we use *one* source, such as a lamp, *which is as wide as two candles* (Fig. 11). We get much the same kind of shadow. There is a dark part in the middle which receives no light. We call this dark part the " umbra." (*Umbra* is the Latin word for shadow.) On each edge of the umbra there is a less dark strip. These parts of the shadow receive light from one side of the source but not from all the source, just as in the experiment these parts received light from one candle but not from two. We call these less dark edges of a shadow the " penumbra." (*Pene*

is Latin for "almost"; pene-umbra means "almost shadow.") The penumbra makes the edges of the shadow less clear. A wide source always causes a pen-umbra. Notice that in Fig. 11 we have marked the *space* behind the object as "umbra." No light comes into this space. If a screen is held anywhere across this space a shadow is formed on it.
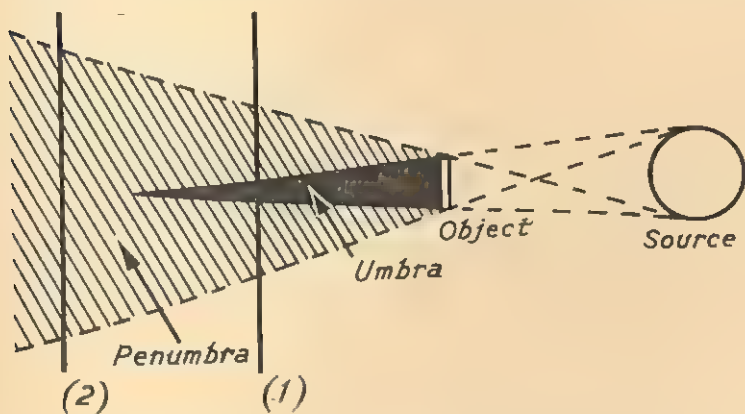

FIG. 12.

If the source is wider than the object, the umbra is pointed and only reaches a certain distance behind the object (Fig. 12). On each side of the umbra, and also behind it, there is a very wide penumbra. If we hold a screen in the position marked (1), the shadow has a small dark middle and wide, less dark edges. If we hold a screen in the position marked (2), the shadow is very large but not properly dark anywhere. You can make these shadows with a lamp and a pencil.

We now pass to the sun, Earth, and the moon, and the shadows which they make. The Earth is a great ball of rock (the distance through it is 8,000 miles) which turns

round once in every 24 hours. The moon is also a ball of rock, but is smaller than the Earth. It is about $\frac{1}{4}$ million miles away and moves round the Earth, in a great circle, once in every 29 days. Although we see the moon shining in the sky at night, *it is not a source of light.* It shines because light from the sun shines on it. The sun is a great ball of very hot gas. The distance through it is over 100 times the distance through the earth. It is about 93 million miles away. We shall need to make drawings which show the Earth, the moon, and the sun. If we draw a circle $\frac{1}{2}$ inch across to represent the Earth, we must draw a circle $\frac{1}{8}$ inch across to represent the moon, and place these circles 15 inches apart. Then the sun would have to be drawn as a circle about $1\frac{1}{2}$ yards across and 160 yards away ! We cannot, therefore, show the sizes and distances correctly in the drawings in this book ; the drawings merely help us to understand the facts about which we read.

As the Earth is a ball, the sun lights up only half of it at a time. The other half of the Earth is in darkness. See the Earth in the middle of Fig. 13. A man standing at X receives light from the sun. But the Earth is turning round. Later the man will be carried round so that sunlight does not reach him ; later still he will be carried into the sunlight again. When we are in the light, of course, we call it daytime, when we are in the dark we call it night.

The moon, we know, does not always seem to be the same shape. Sometimes it seems to be a whole circle, sometimes only part of a circle, or a thin curve, and on some nights, even if the sky is clear, we do not see it at all. If you watch the moon, night after night, you find that it passes through all its shapes, coming back again to the first shape, in about 29 nights. As this is also the

time the moon takes to travel in its circle round the Earth, we guess that the various shapes are caused by this movement.

In Fig. 13 the moon is drawn in different positions round the Earth. The moon takes about $3\frac{1}{2}$ days to
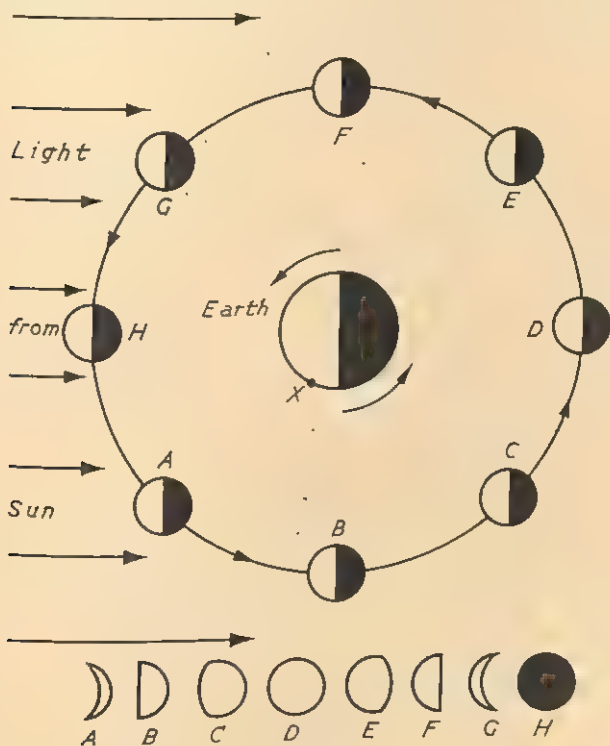

FIG. 13.

move from one position to the next. Half the moon receives light from the sun; the other half is in darkness. Suppose the moon is in the position A and that you are on the Earth looking towards it. What can you see?

You can only see a small part of the bright side of the moon. It looks like the drawing A at the bottom. We call this shape a " crescent." After 3½ days the moon has moved to B. *From the Earth* you can see half its bright side, as shown at B at the bottom. Gradually the moon moves to C, and then to D. We see more and more of the bright part, and when it is at D we see all the bright part. The moon looks completely round. We call this the " full " moon. As the moon moves on to E, F, G, we see less and less of the bright part (see the drawings at the bottom), and when it reaches H we see none of the bright part at all. Then we cannot see the moon. We understand now why the shape of the moon seems to change ; it is because the moon moves round the Earth.

In describing these changes in the appearance of the moon we have left out one rather important fact. Perhaps you have noticed it. We have learned that if light falls on an opaque object, there is a space behind the object where no light reaches, and if anything is placed in this space a shadow is formed on it. There is an umbra (with a less dark penumbra on the edges) behind the Earth. This umbra is pointed in shape because the sun (the source) is bigger than the Earth (the object). Will not the moon sometimes move into this umbra ? We might expect that this will happen when the moon is in the position D.

As the moon travels round and round the Earth it does not keep exactly to the same path. Usually it is a little too high or a little too low to pass through the Earth's umbra. Occasionally, once or twice a year, it does pass through the umbra (Fig. 14). When it does so, a shadow is formed on it. The shadow may cover part of it or all of it. Then we do not see a bright full moon ; part or all of its surface is dark. We call this an " eclipse " of the
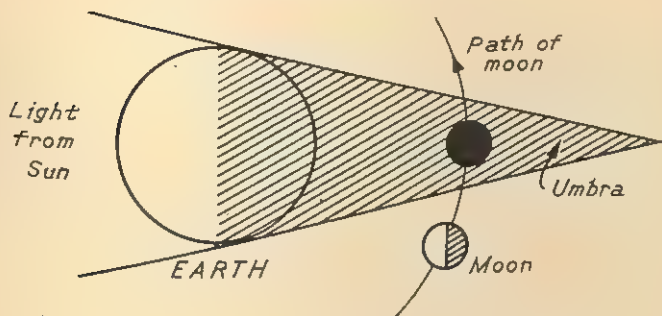
FIG. 14.

moon. It is interesting to note that when the Earth's shadow only covers part of the moon we can see that the edge of the shadow is part of a circle. This helps us to believe that the Earth is round.

There is also an umbra behind the moon. It, too, is pointed, and is long enough just to reach the Earth when
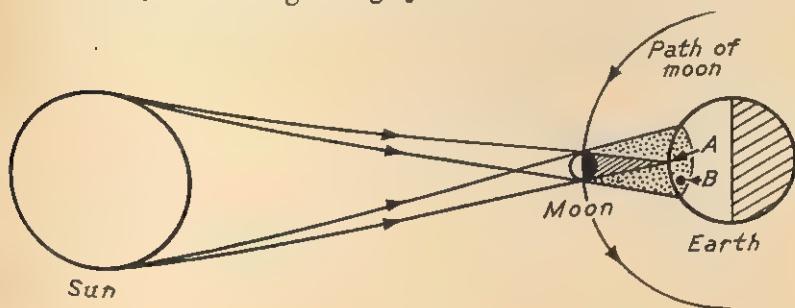

FIG. 15.

the moon is in the position H (Fig. 13). Usually the moon is a little too high or too low for a shadow to be formed by it on the Earth. Occasionally, however, there is a shadow on the Earth. It consists of a small umbra with a wider penumbra round it (Fig. 15). If a man stands

(*Reproduced by permission of Sir Arthur Eddington.*)
Total eclipse of the sun (May 29, 1919).   Notice the great flame at the top.
It was 350,000 miles long.

in the umbra, at A in the drawing, he receives no light
from the sun.   The moon is exactly in front of the sun
(usually for only a few minutes) and the sun is covered up.
We call this a " total " (or complete) eclipse of the sun.
If a man stands in the penumbra, as at B in the drawing,
he can see part of the sun, but the moon covers up the
rest of the sun.   We call this a " partial " (or part), eclipse
of the sun.

Eclipses of the sun do not happen very often, and a total
eclipse is very rare.   The last total eclipse, for example,
which could be seen from England was in 1927, and the next

will be in 1999 ! Total eclipses, however, will be seen occasionally from other countries before then. The covering up of the sun must seem very strange to animals. Men who do not understand it may be frightened, but we see that an eclipse is only a very big example of the well-known shadow.

(Fox Photos, Ltd.)

Whereabouts was the sun when this picture was taken? Can you suggest why the edges of shadow are fairly clear?

REFLECTION OF LIGHT BY MIRRORS

SOMETIMES, when you are out walking, you see something at the side of the road or in a field which is shining very brightly in the sunshine. Perhaps it is a bit of polished metal, such as the clean lid of a tin, or a bit of glass from a broken bottle. After you have walked on a little way, it does not shine so brightly. We know that almost everything throws off some of the light which falls on it, in all directions, but the bit of polished metal or glass sends most of the light in one direction. As you walk along you come to a position where this strong beam comes to your eyes, and then the metal or glass shines very brightly.

In the same way, a looking-glass or mirror throws off most of the light in one direction. You can hold a mirror so that the sun shines on it and send a beam of light in almost any direction you choose.

When an object throws off some of the light which falls on it we say that it " reflects " the light. In this chapter we shall read chiefly about the special reflection of light *in one direction* by a piece of polished metal or a glass mirror. Our first problem is to find out in which direction a flat mirror reflects light.

As we have seen in earlier chapters, we can often find the answer to a problem by doing an experiment. You, yourself, can find the answer to this problem, and to most other problems in this and the next few chapters. You need a piece of apparatus which will send one or two very thin beams of light across a piece of paper on your table.

At the end of the book (page 142) you will find instructions for making such a piece of apparatus. We shall call the thin beams "rays," and the whole apparatus our "light-ray apparatus."

For our particular problem you need a small, flat mirror with at least one straight edge. You can make the mirror stand upright on this edge by fixing it to a piece of wood, or, as in Fig. 16, by pushing one of the ends into a cut in the side of a cork.
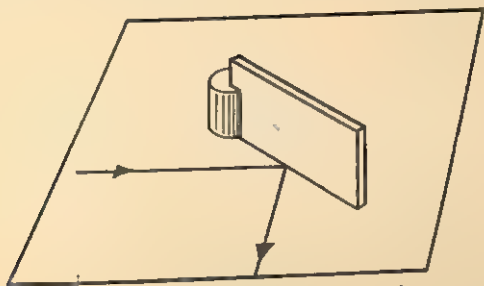

FIG. 16.

Now stand up your mirror so that one ray from the light-ray apparatus strikes it at an angle. The mirror reflects the light and you can see the "reflected ray" on the paper. (In the drawing, arrows show the direction of the ray before and after it is reflected.) Very carefully mark on the paper the position of the ray which strikes the mirror, by drawing a thin, neat line along the middle, and, in the same way, the position of the reflected ray. Also mark the position of the mirror. Then take away the mirror so that you can draw and measure on the paper. From the point where the ray strikes the mirror, draw a line at *right-angles* to the mirror. (This is the line RA in Fig. 17.) Scientists call such a line a "normal," but we will use the simple name
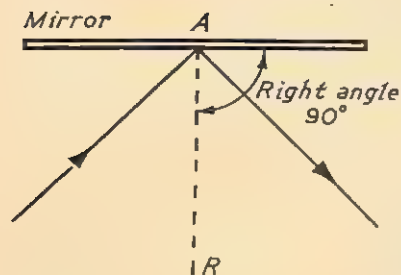
FIG. 17.

" right-angle line " and write it shortly as " RA line." We have now made two angles : one between the ray which strikes the mirror and the RA line, another between the reflected ray and the RA line. Measure these angles with a protractor. What do you find ?

They are equal, or very nearly so.

We must try this experiment several times, making the ray strike the mirror at a different angle each time, before we can be sure that we have found the answer to our problem. We find that, in every experiment, the two angles which we have described above are equal. We have thus found out the direction in which light is reflected by a flat mirror. The reflected ray is in such a direction that the angle between it and the right-angle line is equal to the angle between the ray which strikes the mirror and the right-angle line. We call this fact the *law of reflection.*

A knowledge of the law of reflection tells us how to place a mirror so as to reflect a beam of light in any direction we wish. Suppose, for example, we wish to turn a beam of light through a right angle (90°). We must place the mirror so that the angle between the beam and the RA line is 45°. Then the angle between the
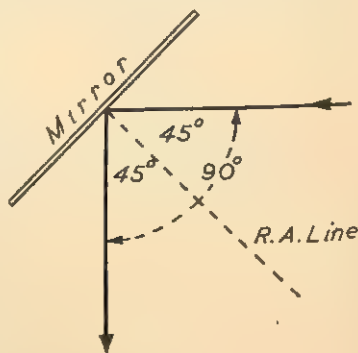

FIG. 18.

reflected beam and the RA line is also 45°, and the beam is therefore turned through 90° (Fig. 18). If a mirror is placed like this near the square corner of a building, or where two roads join at right angles, we can see round the corner by looking into the mirror.

This idea is used twice in an instrument called a periscope. By means of a periscope you can see over a high wall or out of a deep hole in the ground. It consists of a tall tube with a sideways opening at the top and another at the bottom (Fig. 19). A mirror is fixed near the top, and another near the bottom, as shown in the drawing. A man holds the periscope so that the top opening points over the wall or the edge of the hole, and he looks in the bottom opening. Light which comes in at the top is
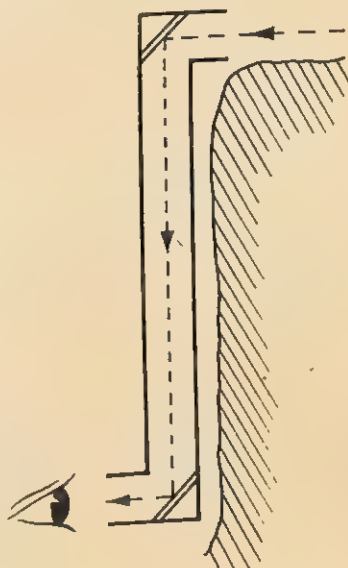

Fig. 19.

reflected downwards by the top mirror, and out at the bottom by the bottom mirror. The man therefore sees things which are over the wall or out of the hole. Periscopes are much used in submarines when moving below the surface of the sea. If the submarine is not too deep in the sea, a periscope can reach above the surface. A man in the submarine can then see other ships on the sea. A submarine periscope usually has a kind of telescope (page 96) inside it so that distant ships seem larger.

Most objects reflect some of the light which falls on them. In what way, then, does a mirror differ from an ordinary object ? An ordinary object, even if it seems smooth, is really slightly rough. The surface of this paper, for example, seems smooth, but actually it is *very slightly* rough. Fig. 20 shows how light which falls on a rough surface is reflected *in all directions*. An ordinary object reflects light in all directions ; that is why we can see the object from all directions. A mirror is almost perfectly smooth. It reflects a little of the light in all directions (we can usually see a mirror wherever we stand), but *most* of the light is reflected in one direction only according to the law which we have learned.
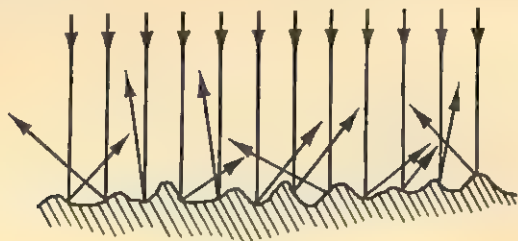

FIG. 20.

All mirrors are not flat ; some are curved. Fig. 21 shows a curved piece of shiny metal. If you look from the side A, it forms a " convex " mirror ; if you look from the side B, it forms a " concave " mirror. The back of a shiny spoon is a convex mirror, the front is a concave mirror. The outside of a shiny cooking pot forms a kind of convex mirror. A convex or a concave mirror can be made of glass with a shiny substance, like that of an ordinary flat mirror, on one side.

It is not easy to get convex and concave mirrors for experiments at home. You may be able to make one

by cutting off a piece of the rim of the lid of a large, round tin. You must take care not to bend the metal as you cut it, and you must choose a tin which is very smooth and shiny.

FIG. 21.

Arrange your light-ray apparatus to give two parallel rays. (Lines are parallel if they run side by side, always the same distance apart, and never meet. Railway lines are parallel.) If parallel rays strike a flat mirror they are still parallel after they are reflected, because each ray strikes and leaves the mirror at the same angle (Fig. 22a). Now hold or stand up a *concave* mirror in the path of the rays. The reflected rays are not parallel. They come towards each other, cross, and spread out again (Fig. 22b).
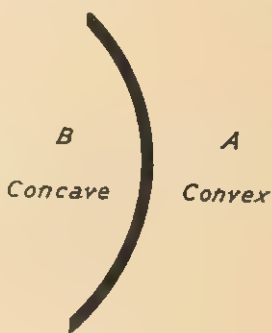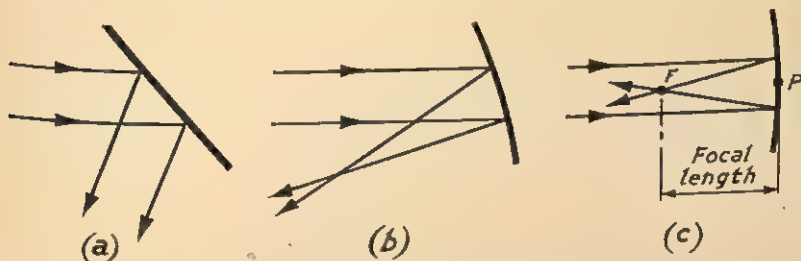

FIG. 22.

All rays which are parallel to each other are reflected so that they pass through the same point.[1] A beam of light with parallel edges, therefore, is reflected so that it comes to a point, and then spreads out again. When light is

[1] This is not quite true if the mirror is very sharply curved.

brought to a point like this we say that it is " brought to a focus " or that the mirror " focuses " the light.

Now turn the concave mirror so that the reflected rays are brought to a focus at a point exactly half-way between the parallel rays which strike the mirror (Fig. 22c). The point F through which the rays pass is a special point. We call it the principal (or chief) focus of the mirror. Measure the distance from the principal focus F to the middle point P of the mirror. We call this distance the " focal length " of the mirror.

While you have the light-ray apparatus arranged to give parallel rays, you can test how these rays are reflected by a *convex* mirror. Stand a shiny, round tin in the path of the rays. The reflected rays are not brought to a focus. They spread out and become wider apart.

Now suppose the rays of light which strike a concave mirror are not parallel. Perhaps they are spreading out. How will the mirror reflect these ? Arrange your light-ray apparatus to give two rays which are spreading out from a point. Place your mirror across the rays as far back as you can. The reflected rays are brought to a focus, but not so sharply as when the rays striking the mirror are parallel (Fig. 23a). Gradually move the mirror towards the light-ray apparatus. The rays are reflected
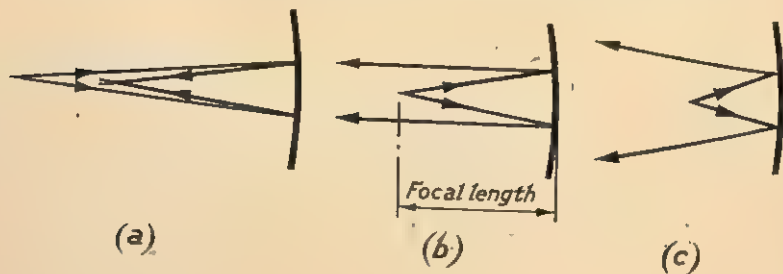

Fig. 23.

inwards less sharply. When the distance of the mirror from the point from where the rays spread out is equal to the focal length, the reflected rays do not come in at all (Fig. 23b). *They are parallel.* When the mirror is nearer still, the reflected rays spread out slightly (Fig. 23c).

The light from an ordinary lamp spreads out in all directions and does not reach far. If you take an ordinary lamp out at night, you cannot see very far by its help because it does not light up distant objects brightly enough. Suppose we put a concave mirror behind the lamp *so that the lamp is at its principal focus.* Some of the light from the lamp strikes the mirror, and this is reflected forwards *in a parallel beam.* As this beam does not spread out, its light is not wasted in all directions. The beam is bright for a long distance.
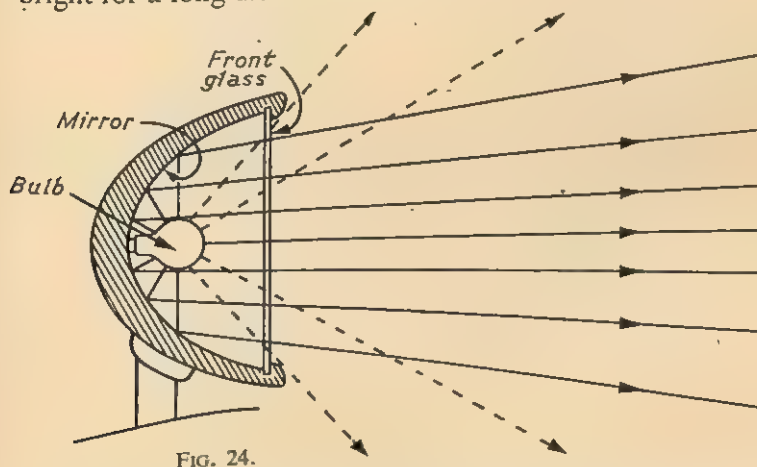

FIG. 24.

The best known use of this idea is in a motor car lamp (or, sometimes, in a bicycle lamp). In a car lamp, a concave mirror, made of very shiny metal, is fixed behind the bulb (Fig. 24). It is called the " reflector." Often

it is fixed a little closer to the bulb than the focal length, so that the beam of reflected light spreads out just a little. The light which comes straight from the bulb does not reach far, but the bright beam of *reflected* light may reach 50 yards or more down the road. A concave mirror is used in the same way to give the bright beam of a search-light.

THE BENDING OF LIGHT RAYS

WE begin this chapter with a little experiment. Place a small object, such as a coin, inside an empty dish on the table. Stand back from the dish so that its side *just* stops you from seeing the coin. Then ask someone to pour water into the dish. The coin can now be seen! How can we explain this strange effect?

We notice that light from the coin passes out of water into air before it reaches the eye. Now we have read that rays of light travel straight. This is quite true if they keep in air, or in water, or in any other transparent substance. It is not true if they pass from one transparent substance to another.

Look at Fig. 25a. It shows a ray of light which passes FROM AIR INTO GLASS. The ray does not travel straight.
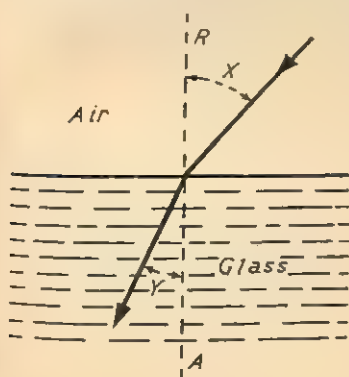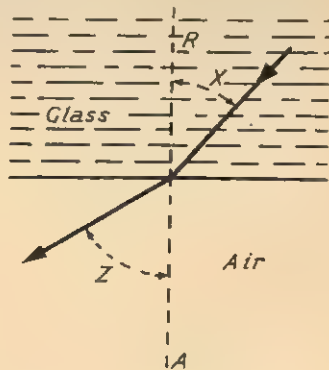
FIG. 25.

It changes its direction as it passes into the glass. How can we describe the direction in which it is bent ? Notice the line RA. It is at right-angles to the surface of the glass and is shown both in the air and in the glass. It is the right-angle line. The angle between the ray in air and the RA line is marked X; the angle between the ray in the glass and the RA line is marked Y. We see that the angle X is bigger than the angle Y. We can say, therefore, that the ray is bent so that it is nearer to the RA line, or it is bent *towards the RA line*.

Now look at Fig. 25b. It shows a ray light which passes FROM GLASS INTO AIR. Again the ray changes its direction, but this time it bends in a different way. The angle Z is bigger than the angle X. The ray is bent *away from the RA line*.

We often use the word " refract " to mean " bend " when we are speaking of light rays. We say that the ray is refracted, or that refraction takes place. A light ray is refracted *towards the RA line* if it passes from air into glass, or into water, or from any transparent substance into another *which is heavier*. It is refracted *away from the RA line* if it passes out of glass or water into air, or out of any transparent substance into another *which is less heavy*.

We are now able to explain the trick with the coin. When there is no water in the dish, light from the coin can- not reach the eye because the side of the dish stops it. You cannot see the coin. When some water is put into the dish, light
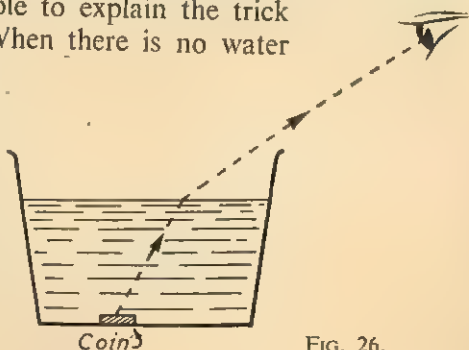

Coin

FIG. 26.

from the coin passes from water into air, that is, from one transparent substance into another which is less heavy. Light rays are refracted away from the RA line. As shown in Fig. 26, light from the coin can now reach the eye. You can see the coin.
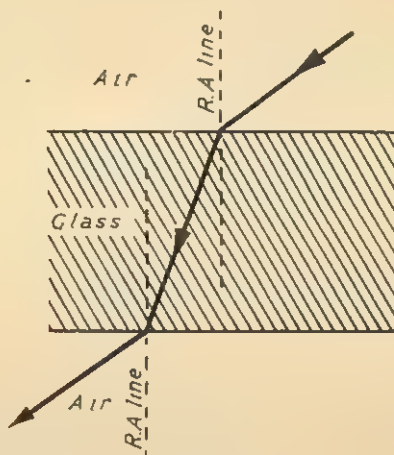

FIG. 27.

Suppose a light ray passes right through a piece of glass with parallel sides (Fig. 27). It passes from air into glass, and then from glass back again into air. It is refracted towards the RA line when it goes in, and away from the RA line when it comes out. The bending of the ray when it comes out is as much as the bending when it goes in, but, of course, in the opposite way. The ray which comes out is therefore parallel to the ray which went in, but, as you can see from the drawing, it is not in the same straight line. It is moved sideways.

You can test this by a simple experiment. You need a medicine bottle, with flat sides, full of water. Arrange

your light-ray apparatus to give one ray and stand the
bottle so that the ray strikes one of the bigger sides at an
angle (Fig. 28a). Notice carefully the position of the ray
which comes out of the water on the other side. It is not
in the same straight line as the ray which went in. The
bottle of water, like the glass of Fig. 27, has moved the ray
sideways. Now turn the bottle so that the ray strikes it at
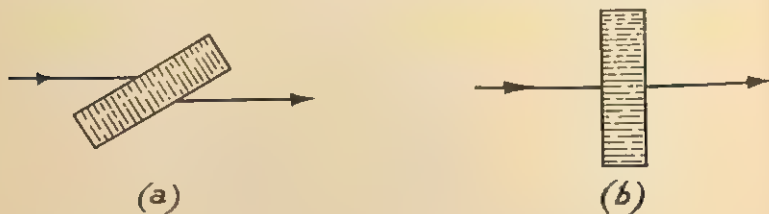right-angles (Fig. 28b). The ray passes straight through.

(a)   (b)

FIG. 28.

It already lies on the RA line, and cannot, therefore, be
refracted towards or away from the RA line.

Perhaps you have noticed that if you look over a fire
in a field at some trees further away, the leaves of the tree
seem to shake. You see the same effect when you look
through the air above the hot engine of a motor car, or
above a road which is very hot in the sunshine. The effect
is caused by refraction. Hot air is slightly less heavy
than cold air. When light passes from hot air into cold
air (or from cold air into hot air) *slight* refraction takes
place. Above the fire (or road, or car engine) there is an
uneven mixture of hot and cold air. Light rays which
pass through this air are slightly bent from side to side.
This makes the things which we see through the air seem
to shake. The stars do not seem to shine steadily. We
say that they twinkle. This effect is caused in much the
same way.

We shall read in later chapters of some of the great uses which scientists have made of refraction. Meanwhile we will turn to another effect. Let us consider in more detail what happens to a ray of light which is travelling in a heavy substance (such as glass or water) and reaches the surface. Look at Fig. 29. A ray of light which is travelling in glass reaches the surface. Suppose it makes a fairly small angle with the RA line (Fig. 29a). It comes out into the air and is refracted away from the RA line.
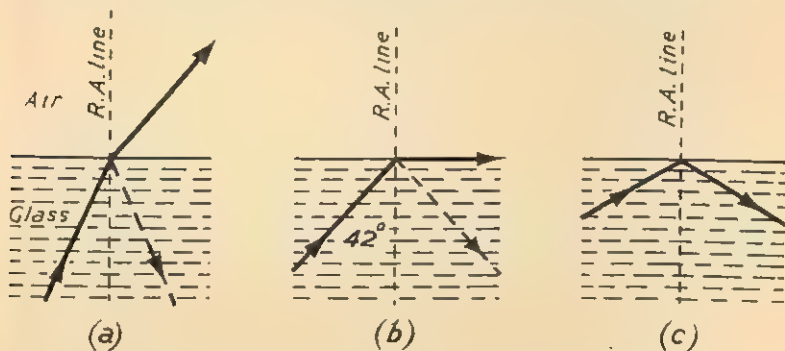

FIG. 29.

Actually a *little* light is also reflected back into the glass. This is shown by the broken line. If the ray in the glass makes a bigger angle with the RA line, the ray in the air is refracted further from the RA line. If the angle made by the ray in the glass is 42°, the ray in the air is refracted so far from the RA line that it lies along the surface of the glass (Fig. 29b). Again, a little light is reflected back into the glass. Suppose the ray in the glass makes an angle with the RA line which is greater than 42°. What happens now? The ray was refracted as far as possible away from the RA line when the angle was equal to 42°; it cannot be refracted further. *The ray does not come out of the glass at all.* Instead, ALL the light is REFLECTED

back into the glass as shown in Fig. 29c. It comes out
at some other place.

Light is reflected back into glass if the ray inside the
glass makes an angle with the RA line which is greater
than 42°. For other transparent substances the angle
is different. For water the angle is 49°, for a diamond
it is only 21°.

Try this experiment. Take a glass jar, such as a jam
jar, and put about an inch of water into it. Stand it near
the edge of the table. Place a small object, such as a
match-box or a coin, behind it (Fig. 30). You can see the
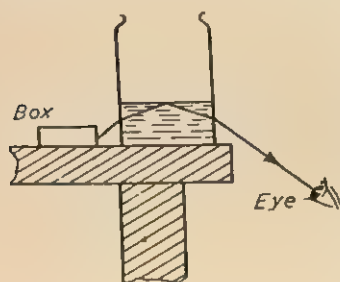object, of course, by looking straight through the water in
the jar. Now lower your
head so that it is *below* the
level of the table. Look
upwards into the water
through the side of the jar.
Again you see the object.
Light from the object goes
into the water, *is reflected
back at the surface* (as
shown in the drawing), and
comes down to your eye.

FIG. 30.

Many uses are made of the reflection of light back into
a transparent substance. The cutting of rare stones to
make jewels is a good example. It is surprising to learn
that about half a diamond is cut away to make it a good
jewel. The diamond must be cut to one of several shapes
which have been found to make it shine as brightly as
possible. When a diamond is cut to such a shape, rays
of light which go in at the top are *reflected* inside, perhaps
several times, and come out of the top again. In what-
ever way the diamond is held it is almost certain that a ray
of light, from a lamp or the sky, will come out to the eye.

The diamond therefore shines brightly as we hold it and move it about.

Fig. 31a shows a piece of glass with three upright sides and a flat top and bottom. We call it a " prism."
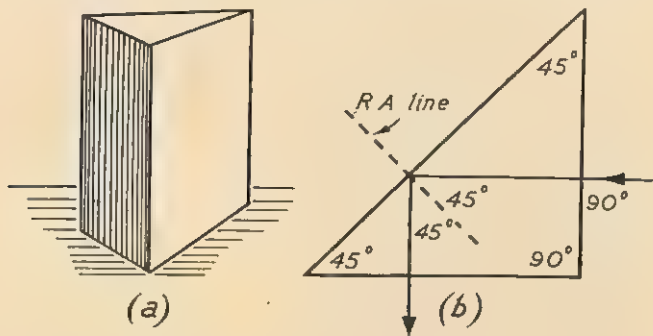

Fig. 31b is a view of the top. In this particular prism the angles of the top are 90°, 45° and 45° as shown. Suppose a ray of light strikes one of the two smaller sides of the prism at right-angles. It goes into the glass, but, because it is already on the RA line, it is not bent. It reaches the opposite, larger side. It makes an angle of 45° with the RA line there, and, as this angle is more than 42°, the ray is reflected back inside the glass. It comes out through the other smaller side. The prism has turned the ray through a right-angle. Compare Fig. 31b with Fig. 18 (page 40). The prism and the mirror cause the same change in the direction of the ray. We can use the prism, therefore, instead of a mirror when we wish to reflect a ray through a right-angle. Two prisms, for example, can be used in a periscope instead of two mirrors. It is interesting to try to draw a periscope with two prisms used in this way.

Prisms of different angles, arranged in other positions, can often be used instead of mirrors. For many purposes prisms are better than mirrors. They are stronger and do not break so easily. Further, the metal paint on the back of a mirror gradually wears off, but no metal paint is necessary on a prism. Perhaps the best known use of prisms instead of mirrors is in a lighthouse. (A lighthouse is built on the sea-shore, or on rocks in the sea, and shines a light to warn sailors of danger.) All the light which leaves the lamp, towards the front, the sides, or the back, is refracted and reflected by the prisms so that a bright, powerful beam of light is sent out from the front over the sea. The picture shows how the prisms are fixed round the lamp.
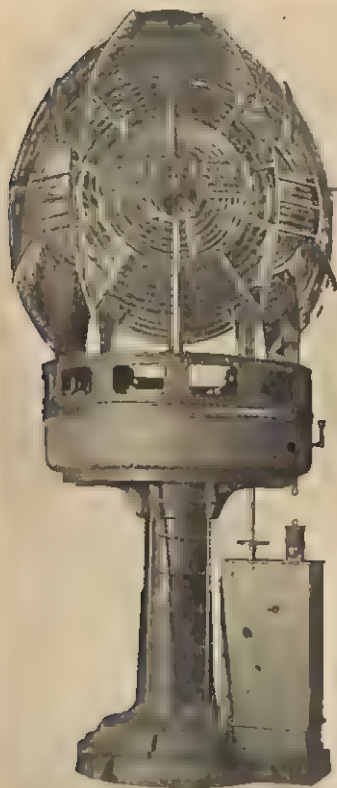
(By courtesy of Chance Bros. Ltd.)

The prisms arranged round a lighthouse lamp.

LENSES

IN our study of refraction so far we have supposed that the surface of the water, glass, or other transparent substance is flat. The surface of a transparent substance might be curved. The *sides* of some water in a jar are curved. You have only to try to look through a glass jar of water at something on the other side of the room to realise that light rays are bent very strangely as they pass through a curved surface. Our problem is to find out in what directions the rays are bent.
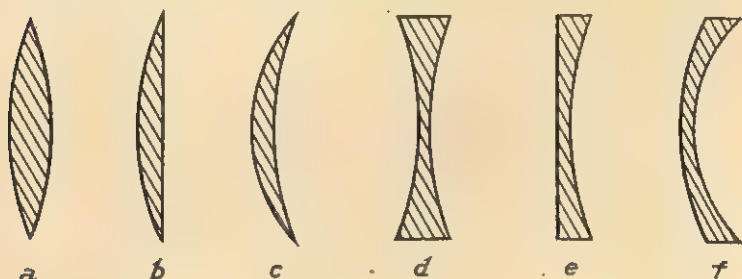

FIG. 32.

An ordinary piece of glass, such as we use for making a window, is the same thickness all over. Fig. 32 is a drawing of some other pieces of glass as you would see them if you looked *at the edges*. These pieces are thicker or thinner in the middle because the sides of the glass are curved. A piece of glass which is thicker or thinner in the middle like this is called a LENS. The " glasses " which some people wear to help them to see are lenses.

A " magnifying glass " (page 91) is a lens. A piece of glass from the side of a bottle is not a lens because, although its sides are curved, it has the same thickness in all places. The first three lenses (a, b, and c) are thicker in the middle. All have at least one side which curves outwards. We shall call all lenses which are thicker in the middle " convex lenses " ; they all bend light rays in a particular way. The last three lenses (d, e, and f) are thinner in the middle. All have at least one concave side. We shall call all lenses like these " concave lenses " ; they, too, all bend light rays in a certain, but different way,.

You may be able to get a lens for your experiments from an old pair of " glasses." Some are convex, some are concave. Perhaps you can buy a magnifying glass. This is a convex lens. The glass in the front of a camera (Fig. 48) is a convex lens.

Pick up your convex lens. You can feel that the sides are curved. Hold it with your arm stretched out and look through it at something on the other side of the room. Everything looks small and upside down ! Keeping your arm stretched out, look at something which is nearer, for example, something 18–24 inches beyond the lens. Unless your lens is very thin, the object looks bigger but still upside down. Now hold your convex lens a few inches above the printing in this book. The printing seems the right way up but much bigger ! Try these experiments with a concave lens. In whatever way you hold the lens, things which you see through it seem to be small and far away, but always the right way up.

We must examine in detail how light rays are bent as they pass through a lens. Let us take a convex lens first. Hold the lens so that one of its sides is towards the sun. Hold a piece of paper on the other side of the lens and move it slowly nearer to or further away from the lens.

In one position there is a small, bright circle of light on the paper. The beam of light from the sun *is brought to a focus* on the paper. After a few minutes this part of the paper may become so hot that it begins to burn. (Fires in the bush may start in this way. A piece of broken glass may act as a lens.) Now set up your light-ray apparatus to give two parallel rays. Send the rays through the convex lens. You see that the rays are brought to a focus (Fig. 33a). The point F is called the principal (or chief) focus and the distance from F to the middle, C, of the lens is called the focal length. Measure the focal length of your lens. A lens with fairly sharply curved sides has a short focal length, but if the sides are very sharply curved a beam of light is not accurately brought to a focus at one point. We sometimes call a lens with a short focal length a " strong " lens because it can bring light to a focus in a short distance.
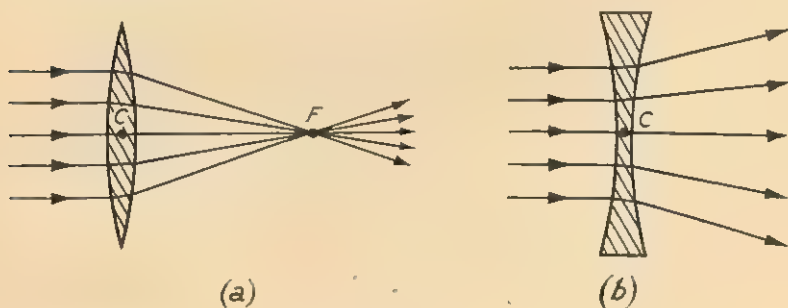

FIG. 33.

Try the same experiments with a concave lens. You cannot bring a beam of sunlight to a focus. Parallel rays are bent so that they spread out (Fig. 33b). The concave lens, therefore, does not bring light to a focus.

Next we must see how a convex lens bends rays of light

which are spreading out before they reach it. Place the lens across the rays as far back as you can. The rays are brought to a focus but at a distance which is greater than the focal length (Fig. 34a). Place the lens nearer to the point from where the rays spread; again the rays are brought to a focus, but at a much further distance from the lens (Fig. 34b). Place the lens nearer still so that the rays spread towards it *from the principal focus.* The rays are bent so that they are parallel (Fig. 34 c.) Lastly, place the lens so that it is even nearer. The rays are bent slightly but still spread out (Fig. 34d). Before you put away your apparatus, send one ray of light through the middle, C, of the lens. You find that unless the ray strikes at a very sharp angle it is not bent.

We notice that a convex lens and a concave mirror act in much the same way. Both can bring light to a focus. This power of the lens to bring light to a focus is very useful. As we shall see, many instruments depend upon this power. A convex lens can also be used *in front of* a lamp, just as a concave mirror can be used *behind* a lamp, to give a strong parallel beam. This idea is sometimes used in an electric torch.

Now hold a convex lens with one side towards a window which is several feet away, or towards a tree which has bright sky behind it. Hold a piece of white paper behind the lens and move it slowly backwards and forwards. You find that when the paper is in a certain position, you get a small, clear picture of the window or tree on it. The picture is quite correct in shape, but it is upside down. We shall call such a picture or copy of a real thing an " image." We can study the image which is formed by a convex lens more easily if we use a lighted candle as the object and work in a room where there is no other light. Stand the candle at one end of the table and support a
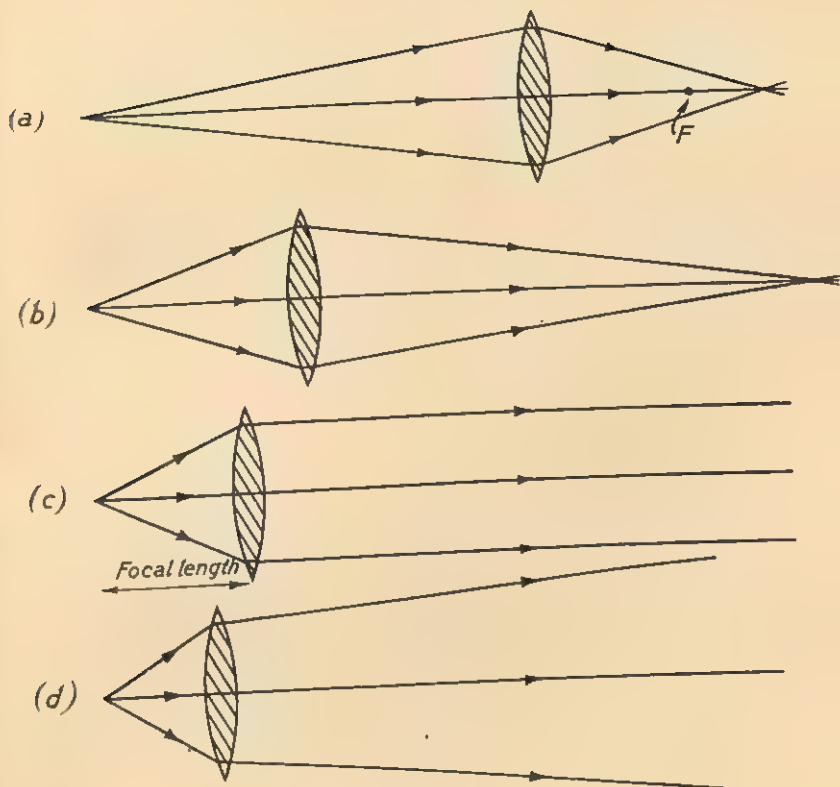
FIG. 34.

piece of paper or card, as a screen, near the other end. By moving the lens forwards or backwards near the screen you can get it into a position so that a small, upside-down image of the candle is formed on the screen.

Why is this image formed? We remember the picture or image which we made by letting light from an object pass through a tiny hole (page 26). Light from each part of the object came to one definite place on the screen.

When the hole was made wider, rays from different parts
of the object were mixed together on the screen.   Now
look at Fig. 35.   All the rays from the top of the candle
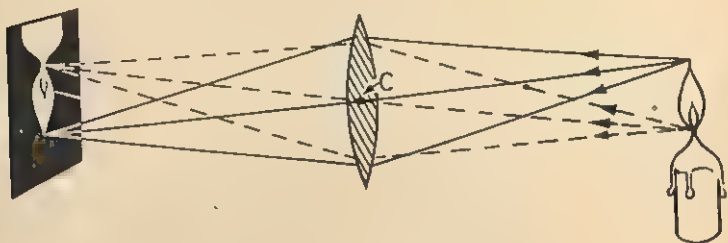*are brought to a focus* by the lens *at one point on the screen.*

FIG. 35.

All the rays from any other part, the bottom of the flame
for example, are brought to a focus at another part of the
screen.   The lens, therefore, stops the rays from mixing
together on the screen, and a clear picture is made.   A lens
is better than a small hole because it can be wide and so
let through plenty of light.

With the candle at the far end of the table the light is
brought to a focus in a fairly short distance (see Fig. 34a)
and the screen must be fairly near the lens.   The image is
small.   Bring the candle nearer to the lens.   The light
is now brought to a focus further away from the lens
(Fig. 34b).   The image is larger.   It is possible to move
the candle to such a position that the rays are brought to a
focus on the wall across the room.   A very large, but
faint (or dim) image is formed there.   We learn two im-
portant facts.   If we wish to form a clear picture, the
screen must be placed so that the rays are accurately
brought to a focus on it.   The image is big if it is formed
a long way from the lens, but small if it is formed near the
lens.

· When the candle is very close to the lens we cannot form an image on a screen. The rays are not brought to a focus (Figs. 34c and 34d).

The convex lens depends upon refraction. Every time we use a lens we are making use of refraction. We can now study some of these uses.
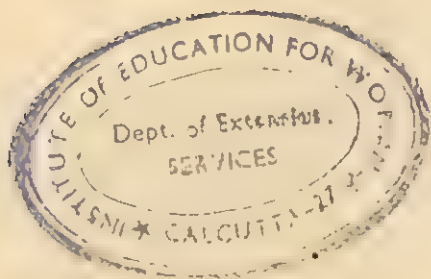
Chapter VII

HOW WE SEE

LIGHT has an effect on most living things. A plant usually grows so as to get as much light as possible. Some flowers turn so as to face the sun, some open in daylight and close at night. Some of the smallest and simplest creatures move towards places where the light is bright, others move to places where it is dark. Most of the bigger creatures have eyes. Our eyes not only tell us when the light is bright and when there is no light. They carefully sort out the light which reaches them so that we learn what things there are around us.

How do the eyes work? Here is a simple story. Look at Fig. 36. The men in the room A of a large building want to know what is happening outside the building. They put a man in a top room B. This man has a box. There is a convex lens in a hole in front of the box and the back of the box acts as a screen. Light from an object outside the building passes through the lens and forms an image on the screen. The man by the box sends telephone messages to the men in the other room and describes the different images which are formed on the screen. In this way the men inside the building know what is happening outside the building.

The building represents the body, the room A represents the brain, and the box represents an eye. An eye chiefly consists of a box, a lens, and a screen. A kind of "telephone wire" joins the screen to the brain. We call this a "nerve." An image is formed on the screen
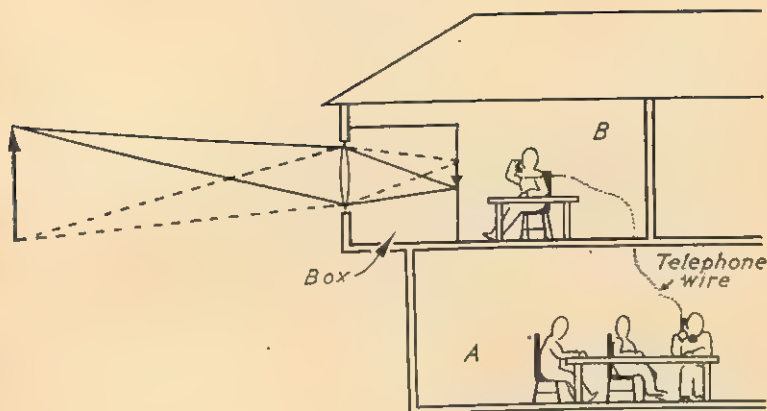
Fig. 36.

and a message travels to the brain. This is how
we see.

If you can get an eye of an animal, such as an ox, from
a butcher you can cut it open and see its parts. In shape
an eye is like a round box or ball (Fig. 37); it is set in a
hollow of the bone in the head. Our eyes are placed so
they both look towards the front. In some animals, such
as the hare and the giraffe, the eyes are placed so much on
the sides of the head that they can almost see as well
backwards as they can forwards. We can move our eyes a
little way up and down and sideways. When you look at
someone's eye you can see three parts: a white part, a
coloured ring (brown or blue), and a black circle in the
middle. The white part is the outside of the " box."
The coloured ring, which is called the " iris," partly covers
the lens. The black circle, which we call the " pupil," is
the hole in the iris through which the light passes. It
seems black because the inside of the eye is dark. A
transparent cover protects the iris and the lens. The lens

is made of a kind of hard jelly. Notice the " muscles."
These are pieces of strong flesh which can pull on the lens.
The special screen is inside the box at the back. We call
it the " retina." A nerve joins the retina to the brain. A
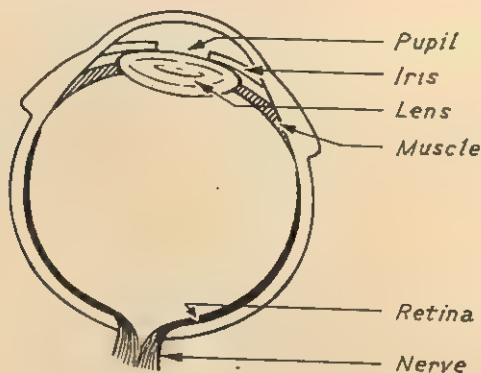clear soft jelly fills the inside of the eye and helps it to
keep its shape.

FIG. 37.

We already know the purpose of the lens, the retina,
and the nerve. What does the iris do ? Light can only
go into the eye through the pupil, and the amount of light
which goes in depends upon the size of the pupil. When
the light is bright the iris closes in and makes the pupil
small ; when the light is dim the iris opens and makes the
pupil larger. We do not decide when the iris shall open
or close. It works on its own. Ask someone to cover
his eyes for a few minutes with his hand. Then, as he
takes his hand away, shine a bright light into his eyes.
You can see his pupils become smaller. The pupils of
the eyes of a cat become very large when the light
is dim. That is why a cat can see so well when it is
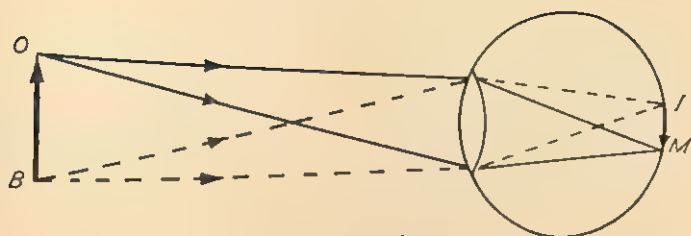nearly dark.

FIG. 38.

In Fig. 38, OB is the object at which the eye is looking and IM is the image on the retina. The image is much smaller than the object and is upside down. Why do we not see things upside down? When the brain receives the message it knows what the message *really* means. We can prove, by a simple experiment, that the brain always judges the object to be the opposite way up to the image on the retina. Make a clear pin-hole in a piece of card. Look towards a bright light, such as a lamp or the sky, and hold the card so that the hole is level with the eye and an inch or so away from it. Carefully hold a pin, head upwards, between the hole and the eye. (You may have to try several times to get this just right.) You see a rather dark pin *with its head downwards* (Fig. 39a)! What has happened? The pin is far too close to the eye for an image to be formed on the retina (see page 61),
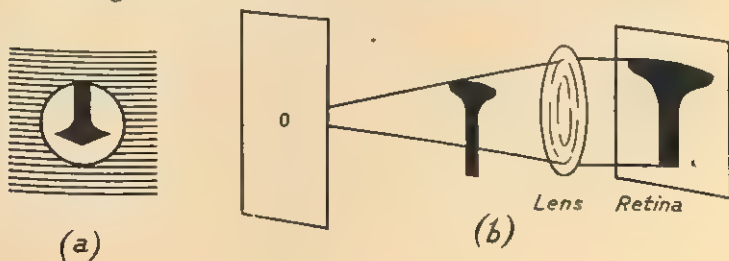

Lens   Retina

(a)

(b)

FIG. 39.

but an *upright shadow* falls on the retina (Fig. 39b). The brain, as usual, judges that the real object is the opposite way up, and so you see a pin head downwards.

The retina is not quite perfect. The place where the nerve actually joins is useless, and if an image is formed there we do not see the object. Try this experiment with Fig. 40. Hold the book up in front of you. Close the left eye and look steadily at the cross with the right eye.

Fig. 40.

Move the book slowly towards you but still look straight at the cross. When the book is in a certain position (about 6 inches away) the black circle disappears. The page seems quite white there. As the drawing on the right shows, when the page is in this position the image of the black circle falls on the retina where the nerve joins. We do not see the circle. We do not usually notice this effect because we have two eyes. The nerve of each eye is towards the nose and if the light from an object falls on the " blind " part of the retina of one eye it does not do so on the retina of the other eye.

We continue to see an object for about $\frac{1}{10}$ second after it has been taken away. If you shake a finger quickly backwards and forwards, all the views of the finger join together. You are still seeing the finger in some positions although it has moved to a new position. In the same way, if you take a stick from the fire and quickly move it round in a circle, you see a complete ring of light. Here is an amusing trick which depends upon our seeing things for a very short time after they have gone. On one side of a piece of card, about 2 inches by $1\frac{1}{2}$ inches, draw a man's head, and on the other side draw a hat at the right height for the head (Fig. 41). Make two holes, about $\frac{1}{4}$ inch apart, at the top, and two more near the bottom. Pass a piece of cotton through the top holes, and another
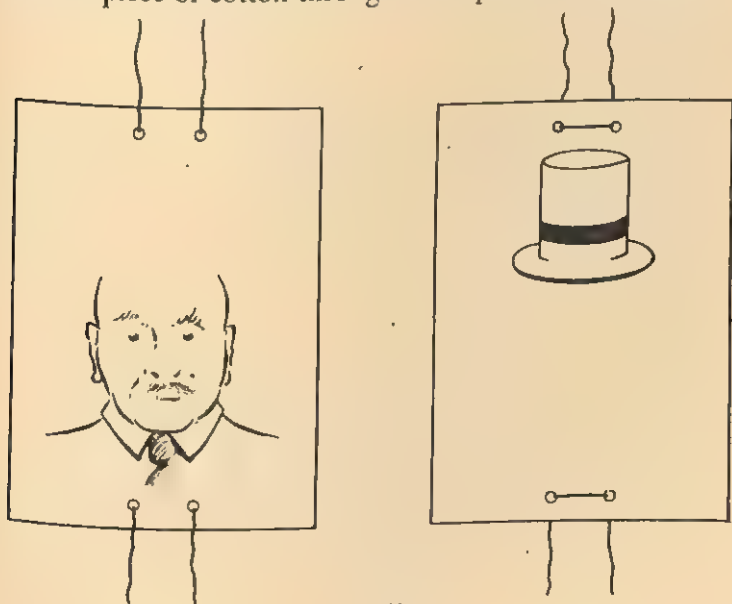

FIG. 41.

piece through the bottom holes, as shown in the drawing.
Holding the ends of the top piece of cotton in one hand,
and the ends of the bottom piece in the other hand, swing
the card round a number of times so that the cotton twists.
Then pull the cotton tight so that it quickly untwists.
The card turns round quickly and you see a drawing of a
man with a hat on !   The card turns so quickly that you
are still seeing the head when the side with the hat has
turned towards you.

We now come to a very important fact.   We know that
we can only see clearly if the image on the retina is clear,
that is, light from the object must be accurately brought
to a focus on the retina.   In the experiment at the end of
the last chapter we learned that if an object moves towards
a lens the position of the images changes.   The screen
must be moved further back.   How is it, then, that we
can see a man clearly when he is across the road, and still
see him clearly when he walks up close ?   Do we move the
retina back ?   Some animals, such as the frog, do change
the distance between the lens and the retina according to
the distance of the object from them.   In our eyes a
different idea is used.   Look at Fig. 42.   In (a), light
from the fairly distant object P is focused on the retina.
Light from a nearer object Q spreads out more sharply
and is not focused on the retina.   In order to focus this
light, so that we can see Q, *we change the shape of the lens.*
We make it fatter and, therefore, stronger.   As shown in
(c), the lens now focuses the light from Q on the retina.
Hold up your finger about a foot in front of your eyes.
If you look at objects on the other side of the room, you
cannot see your finger clearly.   Now look at your finger ;
you cannot then see the far objects clearly.   Can you
feel that something happens in your eyes when you
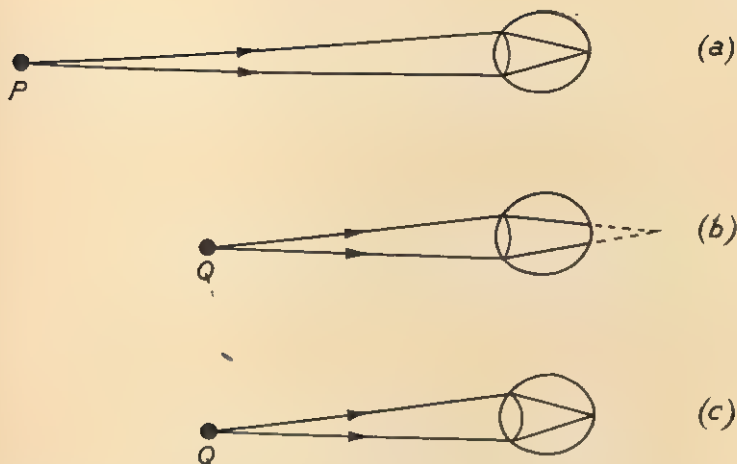change from looking across the room to looking at your

Fig. 42.

finger ? When you do this you change the shapes of the lenses in your eyes.

The lens of an eye is thinnest when we look at distant objects. When we look at nearer objects the muscles (page 64) pull the lens into a fatter shape. It is tiring to pull the lenses of our eyes to a fat shape for a long time. That is why our eyes get tired if we read too much. We cannot make the lenses as fat as we like. Most people cannot see objects clearly if they are nearer than about 10 inches because the lenses cannot be made fat enough.

Our eyes work in a wonderful way. Some people's eyes, however, are not perfect. Some people, for example, can see distant things clearly but cannot see near things clearly. We say that they suffer from "long sight." Some other people can only see near things clearly. We say that they suffer from "short sight." Let us see what causes these troubles and how their sight can be made better.

Perhaps the eye lens is a little thinner than is usual, or the "box" is too short. The person can see distant things clearly by making the lens a little fatter. When he looks at a near object he makes the lens as fat as he can, but the light is not focused on the retina (Fig. 43a). He suffers from long sight. An extra *convex* lens, held in front of the eye, helps to bring the light to a focus (Fig. 43b). These extra lenses, one for each eye, are the well-known "glasses" or spectacles. Old people often suffer from long sight because they lose the power to make the lenses of their eyes fat enough.
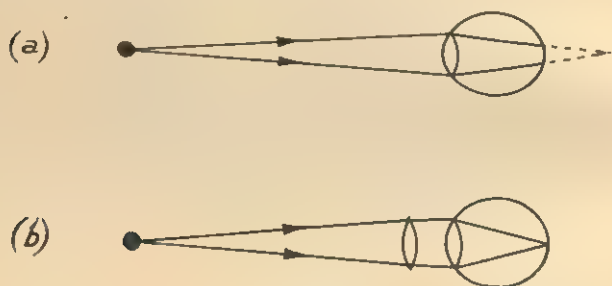

FIG. 43.

If the lens of the eye is fatter than is usual, or the box is too long, the person suffers from short sight. He can always see near things clearly, but when he looks at a distant object the light is brought to a focus in front of the retina (Fig. 44a). He wears spectacles made of *concave* lenses. A concave lens makes light from a distant object spread out a little more widely. The lens of the eye can now focus this light on the retina (Fig. 44b).

The lenses which one person needs as spectacles will not be the same as those which another person needs. It
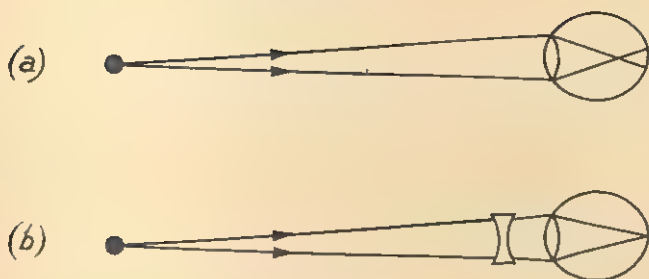
FIG. 44.

is important that the spectacles which are worn should be those ordered by a doctor or other person who understands the kind and focal length needed. Wrong lenses do not help a person to see well and may actually do great harm to the eyes.

When we look at things we judge how far they are from us. When we look across a field, for example, we judge how wide it is, and which trees are near and which are further away. We are helped in judging distances if we know the real sizes of the things at which we are looking. If a tree of a kind we know seems very big, we know that it must be near. If the same kind of tree seems very small, we know that it is a long way from us.

We also judge distances in another way. Stand a match-box near you on the table and a pencil further away. Arrange them so that when you look *with your left eye* you can only see the edge of the box and the pencil seems to be in line with it (Fig. 45a). Without moving your head, close your left eye, and look with your right eye. You now see a little of the side of the box and the pencil does not seem to be in line with it (Fig. 45b). Each eye therefore has a slightly different view; the two eyes do not see exactly the same picture. As our eyes are close

together, the difference of view is not great, especially if things are not near, but it is this difference which helps us to judge distances. Using the two eyes together you can tell immediately that the pencil is further away than the box. Notice also that because the two views are different, you can tell that the box is solid, that is, it has height, length and width.
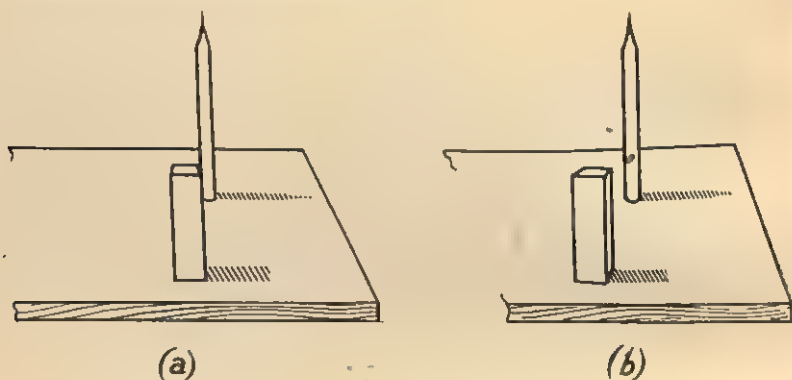

(a)   (b)

Fig. 45.

We know that an object seems bigger when it is near. The size which an object seems to be depends upon the size of the image on the retina. In Fig. 46a IM is the image on the retina of an object OB. For clearness only one ray from the top of the object and one from the bottom have been drawn. We have chosen the rays which pass through the middle of the lens. Now it is fairly easy to see that the size of the image depends upon the angle between these rays, so *the size which an object seems to be depends upon the angle which the top and the bottom of the object make at the eye* (see the drawing). If the angle is small, the object seems small; if the angle is big, the object seems big.
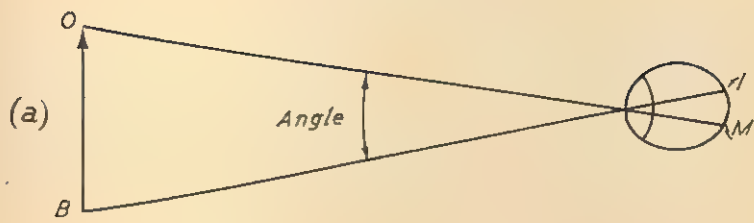
FIG. 46.

A big object, such as a tree, makes a big angle at the
eye if it is near. It seems big. The same tree, if a long
way away, makes a small angle at the eye. It seems small.
A small object, such as a fly, makes a small angle even
when it is near, so that it seems small. You can hold
a match box near your face so that it seems as big as a
tree. Fig. 46 shows why the box and the tree seem
to be the same size. Both make the same angle at
the eye.

Sometimes our eyes play tricks on us. Look at
Fig. 47a. Are the sideways lines parallel, or do they
spread out slightly towards the left? Measure the dis-
tance apart at each end and see if you are right. Which

is the longer sideways line in Fig. 47b ? When you have guessed, measure them with a ruler. We must not blame our eyes when we make mistakes like these. The retina sends a correct message to the brain, but the brain is a little too quick, or a little too careless, in reading the message.

(a)   (b)

FIG. 47.

CHAPTER VIII

PHOTOGRAPHS AND PICTURES

IT was rather more than a hundred years ago that a man made the first photograph. Now we see photographs, and pictures made from them, in newspapers and books more often than we see pictures made by drawing and painting. Now also there are the "moving pictures" which are formed on a screen in a dark place or hall. In this chapter we shall read how photographs and other similar pictures are made.

We use a camera to "take" a photograph. The camera consists of a box with a convex lens at the front and a special screen inside at the back. The camera, therefore, is something like an eye. It differs from an eye, however, in one very important way. No picture is left on the retina of an eye after the image has gone. In a camera, the light causes a change on the screen so that a picture is left on it. Photography (the making of photographs) depends upon the use of special screens.

We all know that brightly coloured clothes often slowly fade in the sunshine. The sun's light causes the colour of the clothes to change. Light causes certain substances to change very much in colour and to change fairly quickly. One of these substances is called silver bromide. It is a white powder if it is kept in the dark. If light shines on it for a few minutes it turns purple or nearly black. Now suppose we mix some silver bromide with gelatine (a substance rather like glue or jelly) and spread it on a piece of paper. If light shines on the paper for a few minutes,

the paper turns nearly black.   Here, then, is a screen which changes when light falls on it.

If light falls on a silver bromide screen for a very short time, for example $\frac{1}{100}$ second, it does not cause enough change for us to see.   If now we put the screen in a certain liquid it turns black just as if the light had shone on it for a much longer time.   We say that we " develop " the screen. After developing, the screen is darkest in the places where the light shone brightest, grey where the light was not bright, and unchanged (white) in places where no light shone on it.

The screens which are most commonly used in ordinary cameras are made by spreading the gelatine and silver bromide on a kind of thin transparent skin.   We call such a screen a " film." It must be made in the dark [1] and wrapped in opaque paper so that light cannot reach it before we use it.   A film is usually about 3 feet long. When we buy it, it is rolled up inside opaque paper on a metal rod or reel.   In Fig. 48 we see the film in the back
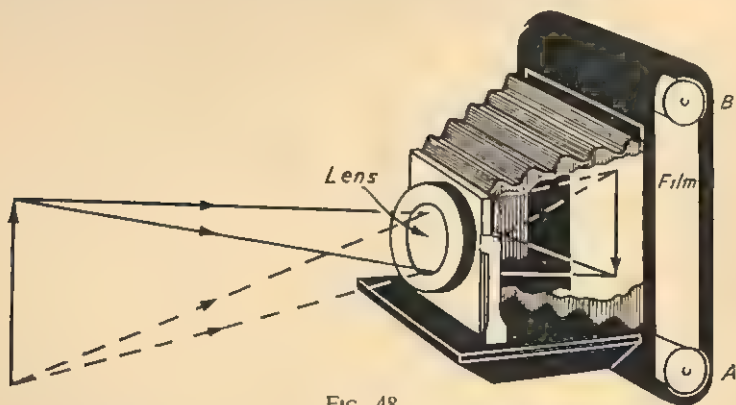

Fig. 48.

[1] Red light has little effect on some films ; these can be made in dim red light.

of the camera.   We wind it from the reel A to the reel B.
In this way we can use different parts of the long film in
turn, and so take a number of photographs (often 8 or 12)
on the one film.

Behind the lens there is a flat piece of metal (not shown
in Fig. 48) which stops light from falling on the film when
the camera is not in use.   When we take the photograph
we press a little lever.   This moves the metal away for a
very short time, usually less than a second, and the light
falls on the film.   In a good camera we can move the lens
a little in or out to make sure that the image on the
screen will be sharp and clear ; in a cheaper camera
the lens is fixed in such a position that the images
of most objects (unless they are very near) are fairly
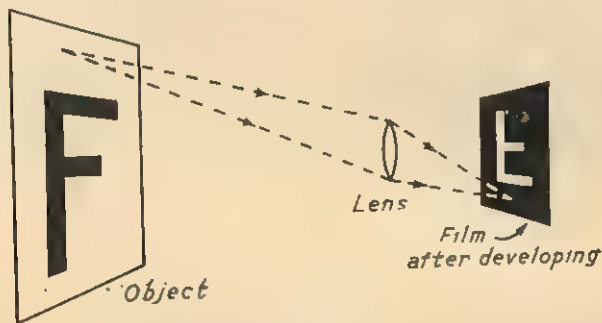clear.

FIG. 49.

After the film has been developed, and any unused
silver bromide washed away, we can see the picture on
the film.   What sort of a picture shall we see ?   Suppose
we take a photograph of a black letter F painted on a piece
of white paper (Fig. 49).   The camera lens forms an image
of the paper and the letter on the film.   Where the light
is bright (from the white paper) the film, after developing,

A printed photograph (left) and the negative from which it was made (right). Notice that the black parts of the photograph are white in the negative, and white parts are black. (This is a photograph of Longmans' office in London).

is black. No light comes from the black F. The silver bromide is not changed, and, after developing and washing, the film is pale and transparent in these places. The " picture " therefore consists of a transparent F with black all round it. (In Fig. 49 we see what the picture is like after developing and washing.) The " picture " is exactly the opposite of the real object. Black parts are pale, bright parts are dark. We call this opposite picture a " negative." The negative, of course, is not itself a satisfactory picture but we can use it to make good pictures.

First, perhaps, we wish to make an ordinary photograph on a piece of thin card. We use a piece of thin card which is covered with silver bromide. We call it " printing paper." Like all other kinds of silver bromide screens, we must keep it wrapped up until we use it. We place the negative flat against it and hold them in a frame with a glass front. We shine light from a lamp on them for a few seconds. Then we take out the printing paper, develop it and wash it, and we find that we have made a proper picture. Fig. 50 helps you to understand how this picture is made. In the drawing the negative has been bent away from the printing paper so that you can see better what happens. The F on the negative is transparent. The light from the lamp passes through the F to the printing paper. After developing, there is a black F on the paper. The rest of the negative is black, and light does not go through it. The paper behind it stays white. In this way we print a black F on a piece of white paper.
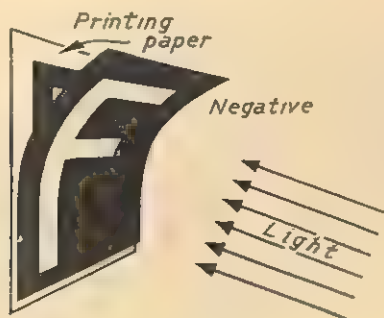

FIG. 50.

It is more difficult to print pictures in a book because the pages are not made of printing paper. Again the

pictures are made from negatives, but the process is very
complicated. Even a simple drawing, like Fig. 50, is
made from a photograph of a drawing in ink.

Now we will turn to the big pictures which are formed
on a screen at one end of a dark room or hall. First we
will study " still " pictures, that is, pictures in which
things do not move. A picture is printed, from a nega-
tive, on a piece of glass. The glass is covered with silver
bromide and then used like a piece of printing paper. We
call this picture on glass a " slide." Slides are often $3\frac{1}{4}$
inches square. Next we have to form a very large copy of
the slide on the screen. Turn back to Fig. 35 (page 60).
The lens forms a picture or image of the candle on the
screen. When the candle is fairly near to the lens (just
beyond the principal focus) the lens forms a very large
image. In the same way, a lens can form a very big
image of a slide *if we light the slide brightly*. We put the
slide in a lantern, that is, a special case or box with a bright
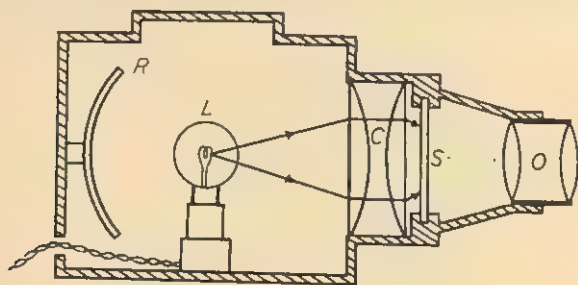lamp inside. Fig. 51 shows the parts of a suitable lantern.

FIG. 51.

The lamp L, which may be an electric lamp or an arc-light
(page 20), is in the middle of the box. The slide S fits
into a place in front of the lamp. The two lenses marked
C bend much of the light from the lamp on to the slide.

Notice also the reflector R.   The lamp thus lights the slide very brightly.   We form an image of this brightly lit slide on the screen by using another lens or, very often, two lenses placed fairly close together.   These are marked O in the drawing.   As the image formed by a lens on a screen is upside down, we place the slide upside down, and then we see the picture the proper way up.
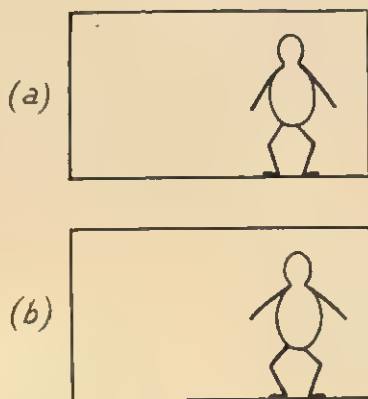

FIG. 52.

In these days, " moving " pictures are more common. We must see how we can make a picture in which parts seem to move.   Cut out about fifty pieces of smooth, thick paper, each 2 inches long and about $\frac{3}{4}$ inch wide.   Lay them sideways.   On the right-hand half of the first one draw a man (Fig. 52a).   On the right-hand half of the second one, *in exactly the same place*, draw a man like the first one but with his arms raised a little higher (Fig. 52b).   Continue in this way on the third, fourth . . . pieces of paper, gradually changing the positions of the arms (or the legs) up and down.   When you have finished

D

all the 50 little drawings, place the pieces of paper *in order* on top of each other so that they form a neat pile. Hold the pile firmly at the left-hand side between a finger and thumb of your left hand. With the thumb of your right hand bend back the right-hand edge of the pile and let the pieces of paper spring up quickly one after the other. Look at the pictures as they quickly come into view. You see a man who seems to be moving his arms and legs ! You can use this idea to make all kinds of amusing " moving " pictures.[1]

The idea depends upon the fact that we continue to see for about $\frac{1}{16}$ second after the object has gone. When the second picture comes we are still seeing the first, though gradually less strongly. As the second picture is slightly different from the first, we think we see one picture in which parts of it move.

The moving pictures on a screen are made by showing many pictures, each one slightly different from the one before, quickly one after the other. Instead of just one slide, we need a long row of slides which can quickly be moved through a special lantern. In some moving pictures, particularly those showing actions of funny animals,[2] thousands of pictures are first drawn by hand. More usually thousands of photographs are taken with a special moving picture camera.

The film in the camera is very long. In big cameras it may be 1,000 feet long. It is wound on a big reel. When the camera is used, a motor pulls the film down the camera, behind the lens, and winds it on another reel. At the same time, the motor uncovers and covers the lens over and over again. In this way, many photographs are taken

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[1] If you like, you can draw the pictures on the top right-hand corners of the pages in a book.

[2] Perhaps you have seen some of the Walt Disney pictures.

A piece of printed film as used for " moving " pictures.

on the long film. The speed is usually arranged so that 24 photographs are taken in every second. The film is developed and washed and the pictures printed on another long film. The picture above shows part of a printed film. Each picture is *slightly* different; the man was moving when the photographs were taken.

The long film of pictures is used instead of the slide in a lantern. A motor pulls it so that each picture stops in front of the lamp for a very short time. A piece of metal moves in front of the lamp while each picture is being pulled into place. Pictures are formed on the screen at the speed of 24 a second, and, as we have described, we think we see one picture in which various parts move.

" Talking " pictures have now become as common as silent pictures. As we look at a picture on the screen we hear voices which seem to come from the people in the

picture. You must read a bigger book if you wish to know how this is done. Another improvement is the making of coloured photographs and screen pictures. In a few years' time, perhaps, coloured pictures will be so common that black and white pictures will be things of the past.

This is the actual size of three of the pictures in the film strip on p. 83. You can see the slight movement of the man's head between each.

Chapter IX

SEEING THINGS WHICH ARE NOT THERE

SEEING things which are not there ! That seems strange.
Perhaps the title of the chapter should be " Seeing things
where they are not," but that also seems strange. Pro-
bably every day you see something, or at least you
think you see something, in a different place from where
it really is. So, whether the title seems strange or not,
we shall read about things with which you are already
familiar.

We know how the eye works. If the beam of light
which reaches the eye is spreading out (from a point which
is not *very* near), or is parallel, the lens in the eye brings
the light to a focus on the retina. Then we see. Further,
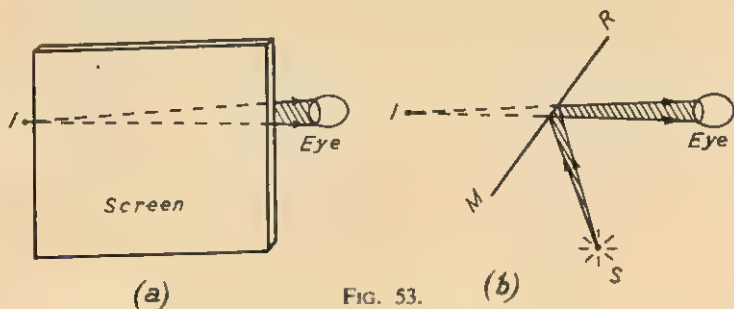we judge from what point the light comes, that is, we judge

(a)   Fig. 53.   (b)

the position of the object at which we are looking. Fig. 53a
shows a wooden screen. We cannot see what there is
behind it, but a beam of light, slightly spreading out,
reaches an eye on the right-hand side. The light is

brought to a focus on the retina ; the eye sees. Further, the eye sees something at the point I because it is from this point that the light seems to be spreading. We do not know if the light really began at I. Perhaps it began somewhere else and was reflected by a mirror or bent by a piece of glass. It does not matter where the light began nor what may have happened to it. *The light which reaches the eye seems to spread out from the point I and so the eye sees something at that point.*

Now what is behind the screen ? In Fig. 53b the screen has been taken away. The source S is near the bottom and the light from it is reflected by the mirror MR. The light does not come straight to the eye, but, as we have agreed, the eye sees something at I. When we look into a flat mirror we think we see things behind the mirror. We see things which are not there ! Although there is no real picture behind a mirror, we call the picture which we think we see an " image."

We next wonder just where, behind the mirror, the image seems to be. Look at Fig. 54. O is a small object in front

FIG. 54.

of a mirror MR. The light from O which is reflected by the mirror seems to come from I. How does the position of I compare with the position of O ? A straight line has been drawn from O to I. It crosses the mirror at the point N. Now we can show by certain experiments,
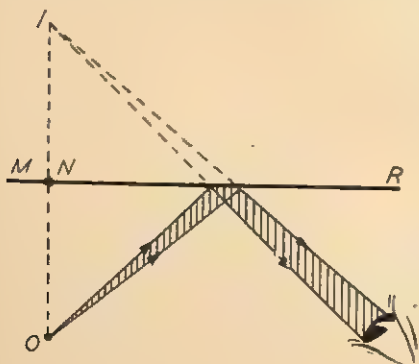
or prove by calculations, that the distance ON is equal to the distance IN. *The image is as far behind the mirror as the object is in front of the mirror.* Further, the line from O to I crosses the mirror at right-angles. So if you stand and look into a mirror which is 3 feet away, you see an image of yourself 3 feet behind the mirror and *straight in front of you.*

The image is turned round sideways
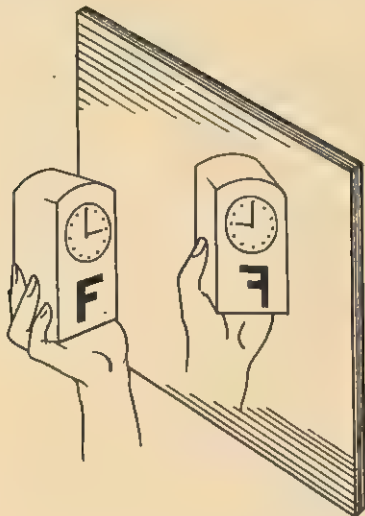
FIG. 55.

The image is the right way up, the same size as the object, indeed it seems at first to be exactly like the object. Let us examine the image more carefully. Fig. 55 is a drawing of a small clock, held in a man's right hand in front of a mirror. The time is 3 o'clock. Look at the image. The clock seems to be held by his left hand, the letter F on the clock is backwards, and the hands of the

clock seem to be in the position for 9 o'clock. *Everything in the image is turned round sideways.* If you have a mark on the right-hand side of your face, there is a mark on the left-hand side of the face in the image. You may wonder what is the strange writing at the bottom of Fig. 55. It is ordinary English writing as seen in a mirror ; it is turned round sideways. One famous scientist (Leonardo da Vinci) did all his writing this way ! Can you suggest a quick way of reading writing like this ?
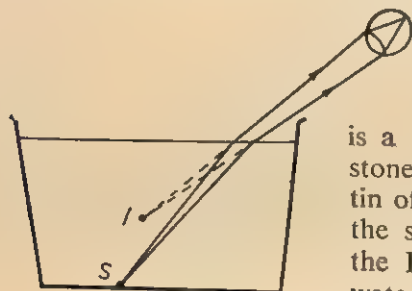

FIG. 56.

There are other ways in which we see things where they are not. Suppose there is a small object, such as a stone, at the bottom of a large tin of water. The light from the stone bends away from the RA line as it leaves the water. Now the eye sees an object according to the direction of the beam of light which actually reaches it. The light from the stone S seems to come from I (Fig. 56), hence the eye sees an image of the stone at I. Notice particularly that the stone seems to be higher than it really is. Stones on the bottom of a clear stream or lake seem to be raised so that the water seems to be less deep than it really is. If you look straight down into some water it seems to be three-quarters of its true depth, and if you look on the slope it seems to be even less deep.

A very interesting example of seeing something which is not there is sometimes met in the desert. A thirsty traveller, looking for water, thinks he sees a pool in the

(A. F. Kersting.)

Reflection by still water. Turn the picture upside down and compare the image with the real view.

distance, and, if there are a few trees, he thinks he sees their images formed by reflection in the water. As he travels on, however, he finds that there is no water. We say that he sees a " mirage." What is the explanation of a mirage ? The air near the hot, sandy desert is very hot. The air above it is a little cooler, and the air above that a little cooler still, and so on. We know that light rays are bent slightly when passing from a cool gas into a hotter gas (page 50), in fact, each layer of air is like a different transparent substance. Light from a distant tree (Fig. 57) is bent slightly away from the RA line as it passes into hotter air and at last it meets a layer of air at such an angle *that it is reflected*. The light then comes up to the traveller's eye. The eye sees an image of the tree just as if the light

were reflected in a pool of water, and the traveller thinks, quite wrongly, that there is water between him and the tree. Even if there are no trees, he might see the image of a bright part of the sky and think, wrongly, he sees a pool of water.
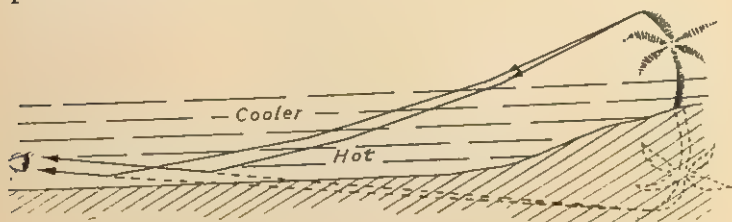

Fig. 57.

We sometimes see the same effect when driving along a hot road. The road, about 100 yards in front of us, seems to be wet and perhaps we see upside-down images of trees. As we drive on, we find that the road is really dry.

Curved mirrors and lenses change the paths of rays of light so that we see things in their wrong places. You remember how, with a convex lens, you saw things upside down (page 56). In the same way, if you hold a shiny spoon a foot or so in front of you, and look into the concave side, you see an upside-down image of yourself and of other things in the room. Fig. 58 helps to explain why we see these upside-down images. (*In Fig. 58 we have only drawn a beam of light from the top of the object*. This is done for clearness. Other beams, of course, come from other parts of the object.) In Fig. 58a the light from the top of the object OB passes through the lens and is brought to a focus at M. We already know that if we hold a screen here the image IM would be formed on it. If there is no screen the light spreads out again. If the light then

reaches the eye, the light seems to be coming from M, and we see an upside-down image in the position IM. Fig. 58b shows how, in much the same way, we see an upside-down image when we look at a concave mirror.
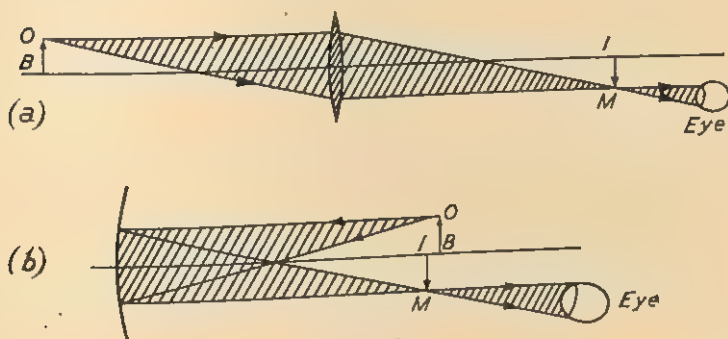

FIG. 58.

The position and size of the image depend upon the distance of the object from the lens (page 60). As rays are only brought to a focus if they come from a source which is further away than the principal focus of the lens or mirror, we only see these upside-down images if the objects are well away from the lens or mirror.

If the object is closer to a convex lens than the principal focus, the light which passes through is not brought to a focus. We see a different kind of image. We remember looking through a convex lens at the printing in the book (page 56). The printing seemed much larger but still the right way up. When we use a lens in this way we call it a " magnifying glass." (" Magnify " means " make bigger.") A magnifying glass is very useful when we wish to look at things which are very small. A watch-maker, for example, uses one when he looks at the small parts inside a watch. Let us see how a magnifying glass works.

A man wishes to see clearly a small object OB (Fig. 59). He brings it near to his eye. If he brings it very near, he cannot see it clearly. In Fig. 59 the object is much too close for him to see it clearly. The man holds a convex lens between the object and his eye *so that the object is inside the focal length*. The light from the top of the object still spreads out a little after it has passed through the lens and reaches his eye as if it came from I. The light from the bottom of the object seems to come from M. The eye sees an image IM. This image is further away from the lens, and the eye can see it clearly, but *the angle which IM makes at the eye is as big as the angle which OB makes at the eye*. He therefore sees an image as big as if the object were at OB, and the lens lets him see it clearly.

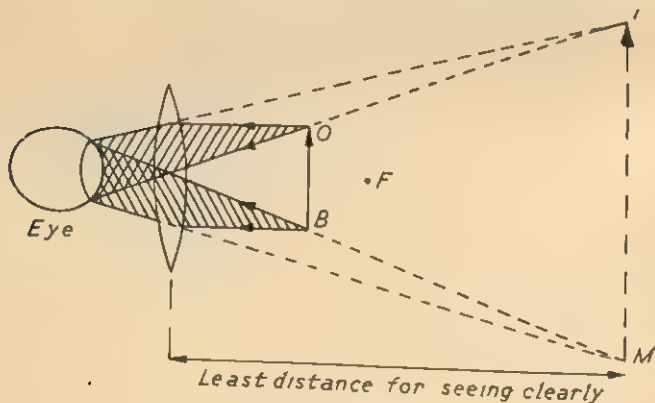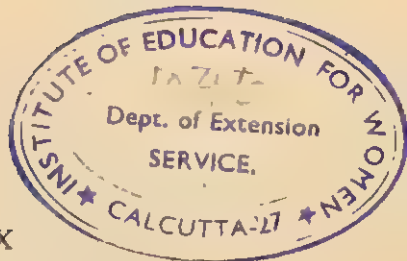Least distance for seeing clearly

FIG. 59.

CHAPTER X

MICROSCOPES AND TELESCOPES

PROBABLY no animal has better eyes than we have, yet there are some ways in which we wish to improve our powers of seeing. We cannot see things which are very small nor things which are very far away, and, of course, we cannot see through things which are opaque. Scientists have invented instruments to help us in all these ways. A microscope enables us to see very small things and a telescope enables us to see very distant things. By means of X-rays, which we shall describe in a later chapter, we can see through many opaque things.

The microscope and telescope both depend upon one idea. First we use a convex lens to make an image of the object which we wish to see, and then we use a second lens as a magnifying glass with which to look at this image. Both instruments, therefore, contain two lenses. The instruments are different, however, in certain other ways, and we must study them separately.

Let us study the microscope first. In Fig. 60, AB is the very small object which we wish to see clearly. The lens L is placed fairly close to it so that a large image CD is formed on the thin paper screen S. Then we look at this image through the magnifying glass M. We could look at it from the front or, as in the drawing, from behind. We see a very large image EF. As the first image CD is bigger than the object CD, and, by means of the magnifying glass, we see an even bigger image EF, each lens helps to make the object seem larger. The microscope depends on this idea.
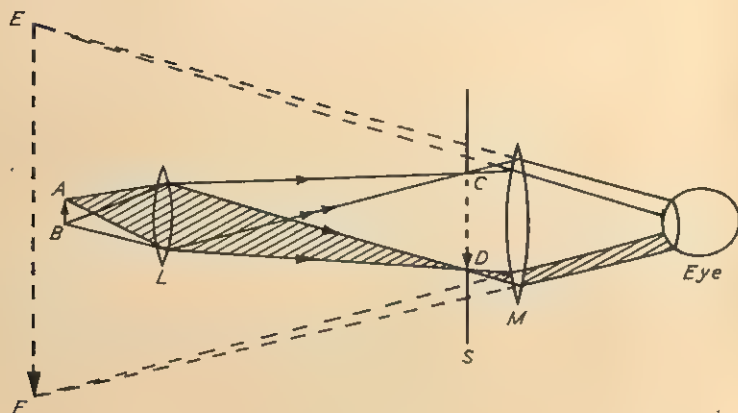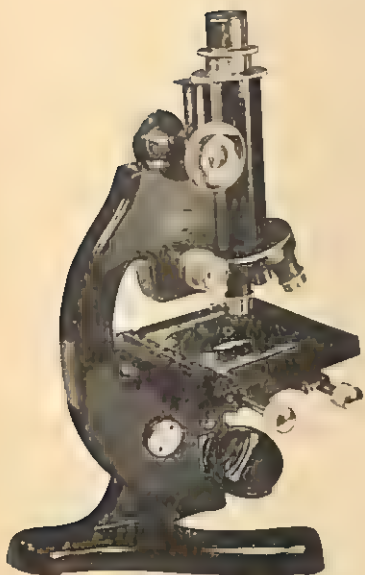
FIG. 60.

The microscope was invented in about 1590. The lenses are placed one at each end of a metal tube. The lens L near the object is called the " object glass " or sometimes the " objective," and the lens M near the eye is called the " eye-piece." As the rays of light travel on from the image CD to the eye-piece, *we do not need the screen S.* In fact we are better without it. It serves no useful purpose and would only stop some of the light from reaching the eye so that the object would seem less bright.

There is a picture of a modern microscope on page 95. The objective has a very short focal length (sometimes only $\frac{1}{6}$ inch, or less) and is usually made of several lenses fixed behind each other. The eye-piece has a fairly short focal length and is often made of two lenses a short distance apart. We put the object which we wish to examine on a little strip of glass and put this on a kind of shelf below the objective. It is important that the object shall be brightly lit. We must also make sure that the objective is the proper distance from the object. If it is not at the

(*Courtesy of Beck, London.*)

A microscope.

(*Fox Photos Ltd.*)

The leg of a bee as seen through
a microscope.

right distance, the image CD (Fig. 60) comes in the wrong
place and the eye does not see a clear, large image EF.
There is a big screw at the side of the instrument. When
we turn the screw, the objective and the eye-piece move
up or down. We turn it until we see as clearly as possible.

A good magnifying glass makes an object seem about
10 times bigger.[1] The best microscope makes an object
seem about 1000 times bigger. With the help of a micro-
scope scientists have learned much about the tiny parts
of plants and animals, and have studied many creatures
which we cannot see with our ordinary eyes.

Now let us consider telescopes. The object which we

[1] Ten times longer and ten times wider.

wish to see is a long way off. We cannot get near enough to it to see it clearly with our eyes. Fig. 61 helps us to understand how a simple telescope works. It consists of two lenses: an object glass and an eye-piece. The object is so far away that we cannot show it in the drawing.
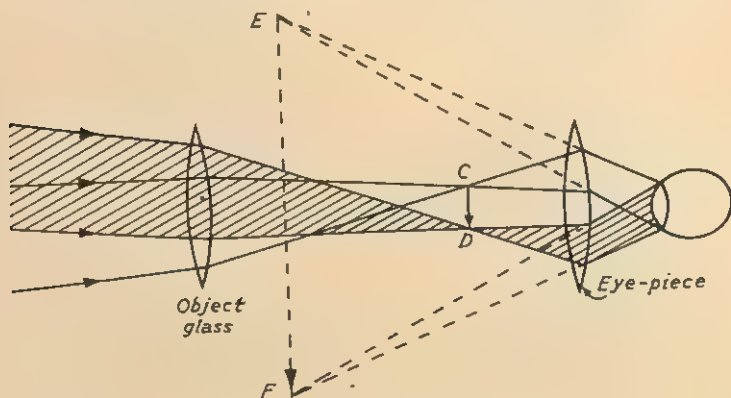

FIG. 61.

The beam of light which comes from the top of the object is shaded. (Actually it spreads out a little, but as the object is so far away the edges of the beam are almost parallel.) The light is brought to a focus at D. In the same way, the beam of light from the bottom of the object is brought to a focus at C. If we put a screen at CD, an image of the object would be formed on it, but, as in the microscope, we do not use a screen. The light travels on to the eye-piece. We use the eye-piece as a magnifying glass for looking at the image CD, and see a large image EF.

The number of times that the object seems bigger is called the " magnifying power " of the telescope. With a telescope used in the ordinary way, the magnifying power is equal to the focal length of the object glass divided by
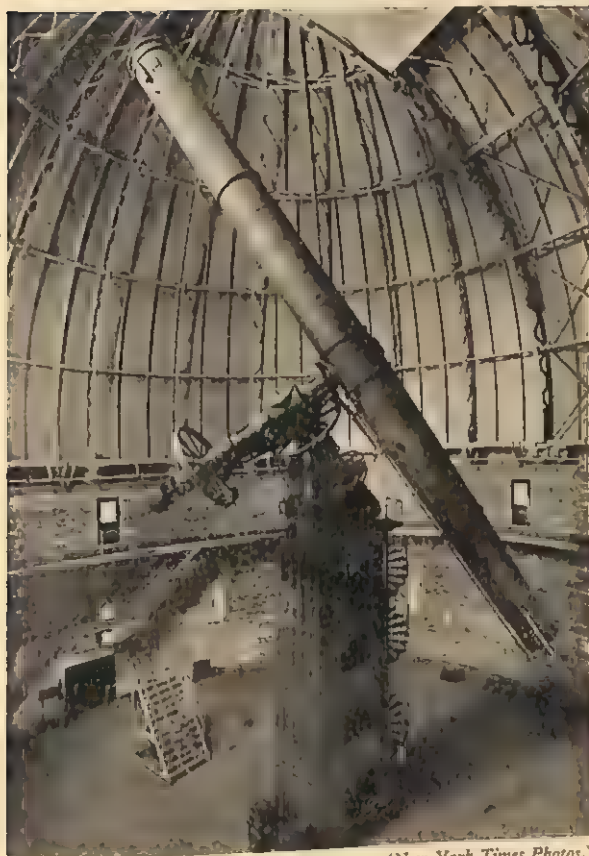
(*New York Times Photos.*)

The biggest telescope using lenses
(at Yerkes Observatory, America).

the focal length of the eye-piece. Thus, if the focal length
of the object glass is 36 inches and the focal length of the
eye-piece is $\frac{1}{2}$ inch, the magnifying power is $36 \div \frac{1}{2}$ or 72.
The lenses would be placed about $36\frac{1}{2}$ inches apart. With
this telescope the moon, for example, would seem to be
72 times bigger. The object glass of a telescope always
has a long focal length so that the magnifying power is big.

We notice that the image which we see through this
kind of telescope is upside down. If we use the telescope
for looking at the stars this does not matter. If we use a
telescope for looking at something on the Earth, as, for
example, a man on a distant mountain, we wish to see the
image the right way up. A telescope for such a purpose
has more lenses or has a concave eye-piece.

When you look through a telescope at the stars at night
you find that they still seem only to be shining points.[1]
This is because the stars are so far away that even through
a telescope they still seem small. When you look through
a telescope for the first time, however, you are surprised
to see many more stars than you can see with your eyes
alone. Why is this ? There are many stars which are so
far away that the light from them is very weak. The
pupil of the eye is never more than $\frac{1}{4}$ inch wide. Not much
light can pass through this small opening, so we cannot
see these faint stars. The object glass of a telescope is
much wider. Much more light passes through the object
glass, and, as you can see from Fig. 61, all the light is made
into narrow beams which can pass through the pupil of
the eye. The eye receives as much light as if it were as
wide as the object glass. We therefore see the dim stars.
A big telescope always has a wide object glass so that it
may receive as much light as possible.

[1] Sometimes one star (as seen by the eye) is found to consist of
several stars.
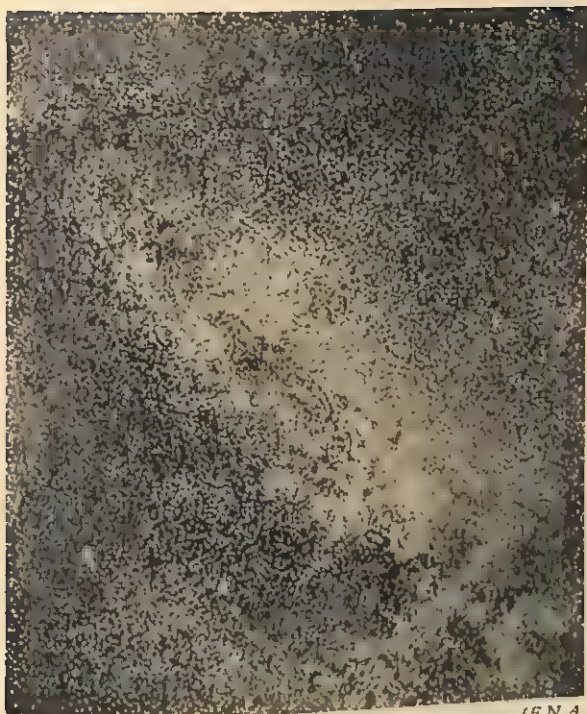
(E.N.A.)

A photograph taken through a telescope of the part of the "Milky Way." Each white point is a star.

The telescope was invented in 1608 by two Dutchmen. Two years later, the great Italian scientist Galileo heard that two lenses could be used to make distant things seem nearer and bigger. He soon found out how to do it.[1] His first telescope had a magnifying power of about 3; later he made one with a magnifying power of 32. (These

[1] He invented a telescope with a *concave lens* as an eye-piece. It has the advantage that the last image is the right way up, but it is not so good in other ways.
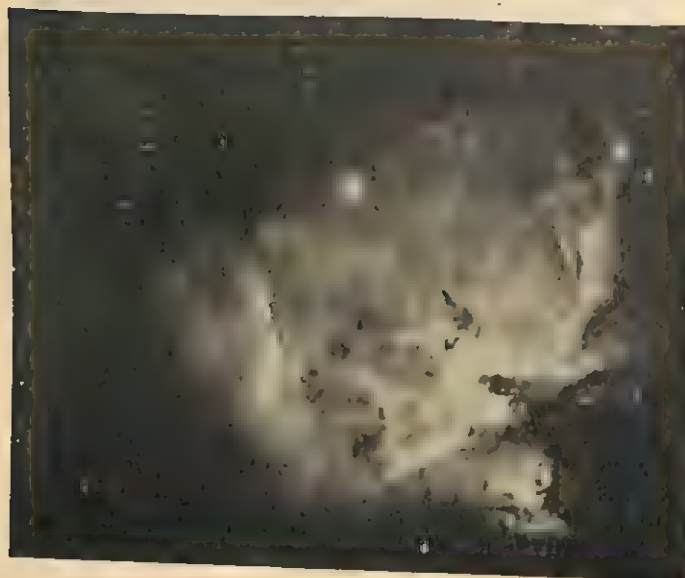
(*Picture Post Library.*)

FIG. 62.

The Great Nebula in Orion. In the group of stars called Orion (Fig. 62) you can just see a dim area of light in the position shown. The picture shows this "nebula," as seen through a powerful telescope. It is a great mass of shining gas.

are very poor compared with telescopes now.) Unlike the Dutchmen, he looked through his telescope at the sun, the moon, and the stars. He saw things which no man had seen before. He saw that the surface of the moon is not flat but that there are mountains and valleys on it. He found that there are sometimes dark marks on the sun and that Jupiter (which is another "planet" like the Earth and also moves round the sun) has several "moons."

The object glass of Galileo's best telescope was probably about $2\frac{1}{2}$ inches wide. Since then, particularly in the last hundred years, very big telescopes have been built. The biggest telescope of the kind we have described was built in America in 1897. The object glass is 40 inches wide and has a focal length of 62 feet. It is difficult to make such a large piece of glass clear and even. Further, such a lens is very heavy, and, as it has to be supported *at the edges*, it may bend in the middle and get out of shape.

We know that a concave mirror can bring rays of light to a focus in much the same way as a convex lens (page 58). In Fig. 63a there is a concave mirror M at the end of a
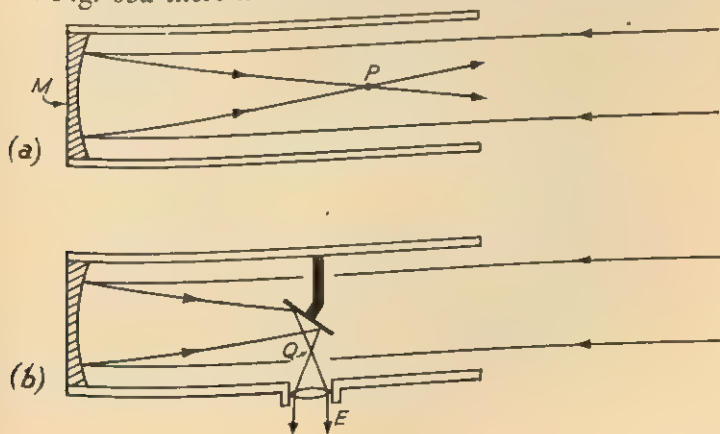
FIG. 63.

tube with its reflecting side inwards.   Light from a distant
star is reflected by the mirror and brought to a focus at P.
An image of the star is formed at P.   If we can look at
this image through a magnifying glass we have made a
telescope.   The difficulty, of course, is to get near to P
without getting inside the telescope and stopping the light
from coming in !   Fig. 63 shows one of several ways of
solving this difficulty.   Inside the telescope there is a small

(*Picture Post Library*.)
The great reflecting telescope on Mt. Wilson (America).

flat mirror at an angle. It stops a little but not much of the light which comes into the telescope. The mirror reflects the light again and the image is formed at Q. We can then look at this image through the eye-piece E *in the side* of the telescope tube.

Isaac Newton (page 104) invented this kind of telescope in 1668. He realised that the telescope would be shorter, and, unlike telescopes at that time with lenses, the image would be very clear. The telescope which he made was just over an inch wide and the mirror, which was made of metal, had a focal length of $12\frac{1}{2}$ inches. The telescope is still kept at Cambridge University.

The chief advantage of a reflecting (or mirror) telescope is that a large mirror can be made more easily than a large lens, and, as light does not go *through* a mirror, a heavy mirror can be supported underneath. The biggest reflecting telescope in the world is on Mt. Wilson in America. The mirror is 100 inches across. (Compare this with the world's largest lens.) In 1934 men began to make a mirror 200 inches across. The telescope, which is to be built on Mt. Palomar in America, is nearly finished.

COLOUR

LIGHT, we know, can be of different colours. A stick which is taken from the fire gives out red light, a candle flame gives out yellow light. Sunlight is *very slightly* yellow, but it is convenient to call it white light. The grass in the field seems green when sunlight falls on it. How does the grass make green light from the white sunlight ? Why does the clear sky seem blue, and why, at sunrise or sunset, does it seem red and yellow ? These are the kind of questions we shall now try to answer.

Isaac Newton was a very great English scientist. He lived from 1642 to 1727. We remember him best for his .studies of falling objects and of the movements of the Earth and the moon, but he also studied light and colours. One of his experiments is famous. He covered the windows of his room with wooden screens but left one very small hole through which the sun could shine. He held a glass prism (page 53) in the path of the thin beam of sunlight which shone through. The light changed its direction as it passed through the prism and shone on a screen on the other side of the room. Further, the beam of light spread out after leaving the prism so that, instead of lighting up one little part of the screen, it lit up a strip. This strip was not white ; it was a row of different colours ! Newton named the colours which he could see. He saw red, orange, yellow, green, blue, indigo (a very dark blue), and violet. Fig. 64 shows Newton's experiment. We see the strip of colours on the screen. We call such a strip of colours a " spectrum."
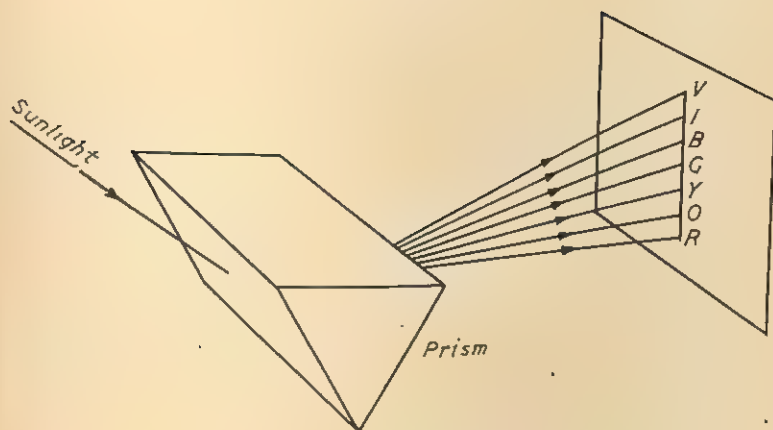
Fig. 64.

We can understand why the beam was bent. The light was refracted as it went into the glass, and again as it came out. But why was a spectrum formed on the screen? The glass was quite clear; it could not have made the colours. Newton realised the answer. *White light is a mixture of light of different colours.* When this mixture of light comes into our eyes we cannot see the colours separately. We call the mixture "white." A prism, however, separates the colours in white light. It does this by bending light of each colour by a different amount. Look at Fig. 65. The prism bends red light least; it bends violet light most. Light of each other
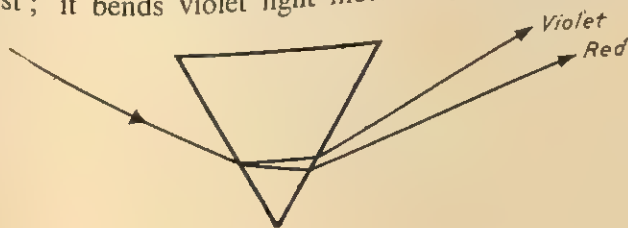

Fig. 65.

colour (not shown in the drawing) is bent by a different amount between these two. In this way light of each colour goes to a different part of the screen so that we can see the colours separately.

When you see a spectrum of white light for the first time, you notice particularly how bright the colours are. You notice too that each colour *gradually* changes into the next. One end of the spectrum is dark red. Then come lighter kinds of red, then reddish-orange, then orange, then dark yellow, yellow, and so on. It is strange that Newton named only seven colours in the spectrum and that he chose to name two kinds of blue but not two (or more) kinds of each of the other colours. It is convenient for us to speak of the seven colours of the spectrum (and we shall often write them shortly by their first letters, thus, ROYGBIV) but we must remember that actually there are many colours.

Newton found out that white light is a mixture of light of various colours. If seven beams of light, one of each of the colours ROYGBIV, come into the eye together, the light mixes on the retina and we see " white." Suppose we have seven lamps, each giving light of one of the seven colours, and make them shine on the same part of a piece of white paper. Light of each colour comes from the paper into the eye. We do not see the separate colours; the paper looks white. Here is a more simple way of showing that when beams of the seven colours ROYGBIV come into the eye at once we see " white." Cut a circle about 2 inches across from a piece of thin white card. Divide it into seven parts. Use paints or coloured pencils to colour one part red, one orange, one yellow, and so on (Fig. 66a). The colours must be bright and pure.[1]   Make a small hole in

[1] The green, for example, must not be slightly yellow or slightly blue, but a true, clear green.

the middle of the circle and push a piece of a match (about $1\frac{1}{2}$ inches long) part way through the hole (Fig. 66b). You can now spin the card like a top. As it spins, beams of seven colours come into the eye. What colour does the
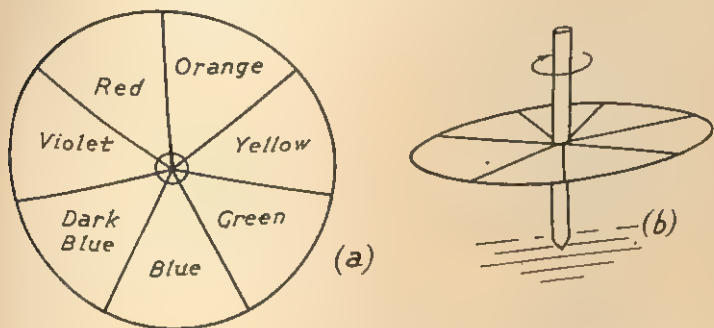

Fig. 66.

card seem to be? If the colours are very bright, and you have the right amount of each, the card seems white. (If your colours are not bright enough, the card may seem to be a pale grey. If it seems slightly blue, or slightly pink, make another one with less space coloured blue, or red, and try again.)

You can try some more experiments with little tops like these. Make one with half the circle red and the other half blue. The top seems purple when you spin it. Purple light is a mixture, therefore, of red light and blue light. Half blue and half green make a pretty bluish-green colour. Try half red and half green. What colour, do you think, will the top seem to be? The answer, you find, is yellow or orange. So yellow light *may* be pure yellow or it may be a mixture of red light and green light; usually it is a mixture of red, orange, yellow, and green light. You must remember that in these experiments two differently coloured *beams of light* mix and enter

the eye together. *This is not the same as mixing two different paints or dyes*. We shall discuss dyes and paints later.

Sometimes, when it is raining, but the sun is shining through a clear part of the sky, we see a coloured half-circle of light in the sky. We call it a rainbow. Its colours are those of the spectrum. The colours in the white sunlight have been separated, not by a glass prism, but by the drops of rain.
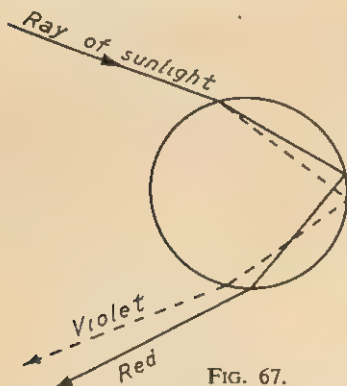

FIG. 67.

Let us see what happens when a ray of sunlight strikes a round drop of water (Fig. 67). The light is bent as it goes into the drop, but, as light of each colour is bent by a different amount, *the colours are separated.* In Fig. 67 only the red ray (whole line) and the violet ray (broken line) are drawn ; rays of the other colours lie between these two. The rays are reflected at the back of the drop. They are bent again as they come out of the drop.

The rays of different colours from one rain-drop spread out so much that they are yards apart when they reach the ground. The eye only receives light of *one* colour from *one* drop. Now look at Fig. 68. If the red ray from the drop A comes to the eye, the violet ray from this drop passes over the man's head. The violet ray from the lower drop B, however, comes to the eye. Other drops between A and B send rays of other colours to the eye. We thus see the colours of the spectrum in the sky between A and B. In the same way we see a spectrum between

the drops C and D, and between any other similar pairs of drops. We thus see a big coloured curve or rainbow in the sky. We only see a rainbow if the sun is behind us and is fairly low in the sky. Sometimes we see a second, rather dim rainbow outside the chief rainbow. This is formed when rays of sunlight strike some of the rain-drops at such an angle that they are reflected *twice* inside the drop.
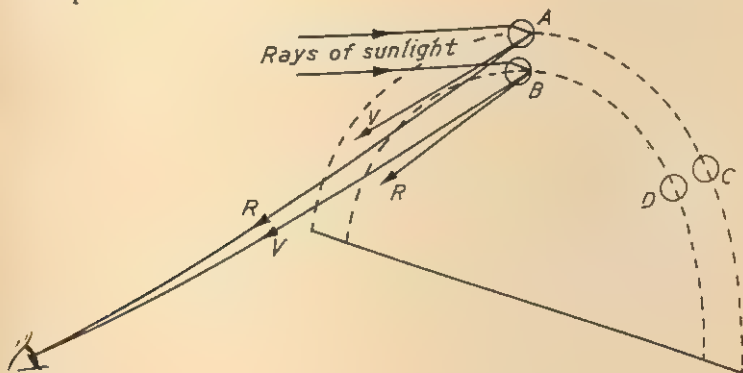

FIG. 68.

We have learned that white light is a mixture of colours, of which we usually name seven, and that a prism or a rain-drop can separate these colours. We now have to explain why ordinary things, such as grass and flowers, books and clothes, are coloured when white light falls on them.

Let us first think about the red lamp on the back of a car or bicycle. The lamp itself makes white light but only red light comes through the red glass. The red glass has not, in some strange way, changed the white light into red light. The explanation is easier than that. Of all the colours in white light (ROYGBIV) only the red part (R) can
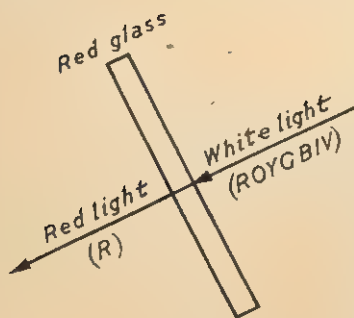
FIG. 69.

get through the glass (Fig. 69). The glass stops and *takes away* the other parts (OYGBIV). In the same way, if you hold a piece of green glass in a beam of white light, only the green part of the light can pass through. The green glass takes away the other parts (ROYBIV). Coloured glass " makes " coloured light by *taking away* other colours from white light.

Now let us consider ordinary objects. We say, perhaps, that a certain flower is red. We mean that when white light falls on the flower, only red light comes from it to the eye. Why should only red light come from the flower ? The flower acts in much the same way as a piece of red glass. White light (ROYGBIV) falls on the flower. The flower *takes away* six of the colours (OYGBIV) and only reflects the red part of the light (Fig. 70a). (As the flower is rough the red light is reflected in all directions.)
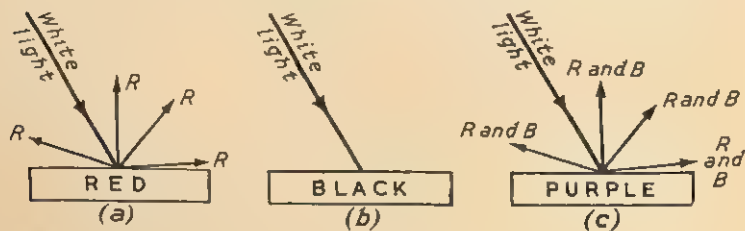

FIG. 70.

A piece of cloth, perhaps, is blue. When white light falls on the cloth, the dye in the cloth reflects the blue part of the light (and perhaps the indigo); it takes away the

other parts (ROYGV). A piece of white paper, of course, reflects all the colours, and takes away none. The black printing in this book takes away all the light which falls on it and reflects none (Fig. 70b). Black things reflect no light. " Black " therefore really means " no light." Some flowers have a bright purple colour. The dye in the flower takes away all the colours of the white light except red and blue. The red and blue parts of the light are reflected (Fig. 70c). When rays of these colours come to the eye together we see " purple " (page 107). Can you now explain why the grass is green ?

We often mix paints to make paint of another colour. Blue paint and yellow paint, for example, make green paint. Why is this ? Ordinary paints are never of a perfectly pure colour. Blue paint reflects blue light chiefly, but it also reflects a little green light and violet light (the colours on each side in the spectrum). In the same way, yellow paint reflects a little red, orange, and green light, as well as yellow light. Let us write down these facts in the following way :

Blue paint absorbs ROY. Yellow paint absorbs BIV. The two paints *mixed together* absorb ROY and BIV so that only green light is reflected from the mixture. The mixture, therefore, seems green. We can explain the effects of mixing other paints in a similar way.

When we say that an object is red, or green, or some other colour, we mean that the object seems to be of that colour when white light falls on it. An object may seem quite different if coloured light falls on it. On a piece of white paper, make a drawing with red paint or pencil and another with green paint or pencil. Shine red light (only) on the paper. (You can use the back lamp of a bicycle.) You cannot see the drawing in red ; the drawing in green seems black. Both the white paper and the red drawing

reflect red light. You cannot tell the difference between them. The green drawing takes in the red light. It can only reflect green light, but there is no green light. So no light comes from this drawing and it seems black. It is interesting to look at other objects, such as the Union Jack flag, when only red light falls on them.

We do not often see things in red or green light, but the light from most ordinary lamps is usually rather yellow. The light from the lamp contains all the colours ROYGBIV but there is not enough blue and violet light for the light to be white. For this reason, the colours of some objects seem slightly wrong when we look at them by the light of a lamp. Dark blue things often seem black. Lamps can be made which give light almost like sunlight. We described one such lamp on page 22. We call them "daylight lamps." They are used in some shops in some countries, particularly in those shops where women buy coloured clothes, and in large buildings and some hospitals where men must have a good light for their work.

We have still to explain why the clear sky is blue, and why, at sunrise and sunset, parts of it are often red and yellow. The air which is round the Earth has no colour. It does not take away some of the colours of sunlight like paint does, but it separates the colours in another way.

The next time you see a good fire burning in a field or in the bush look carefully at the smoke. First stand with your back towards the sun or the brightest part of the sky. The smoke seems blue-grey in colour, especially if there are dark objects, such as trees, behind it. Now stand so that the smoke is between you and a bright part of the sky. The smoke seems red-brown. The sun, when seen through smoke, seems dark orange or red. We explain these colours in the following way.

Smoke consists of many *very small* bits or particles. When light strikes small particles it is reflected off them in all directions. We say that the particles " scatter " the light. Now *blue and violet rays are scattered by small particles much more than red and yellow rays.* Blue and violet rays are scattered sideways and even backwards ; most of the red and yellow rays travel straight through the cloud of particles. (Fig. 71) If, then, you stand so that
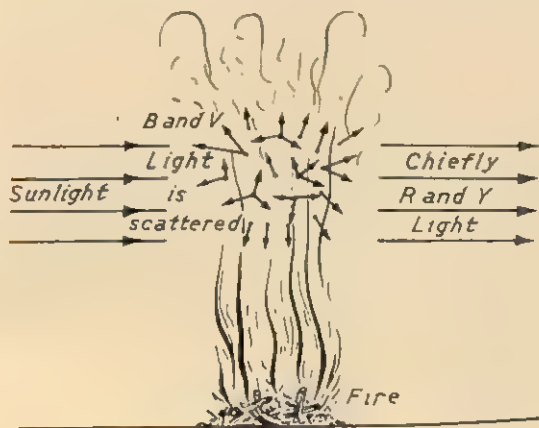

B and V
Light
Sunlight *is*
scattered
Chiefly
R and Y
Light
Fire

FIG. 71.

the brightest sunlight comes from behind you, some of the blue [1] light is scattered back to you. The smoke seems slightly blue. If you stand so that the light which reaches you has passed through the smoke, the smoke seems slightly red, because red and yellow rays come through best.

Now the air contains particles. There are particles of dust, tiny drops of water, and the particles of the air

[1] Violet light is also scattered, but as violet is not a bright colour, you do not notice it with the blue light.

E

itself. As the air is so thick, reaching to several hundred miles above the Earth, there are enough particles to scatter rays of sunlight just as smoke does. Look at Fig. 72.
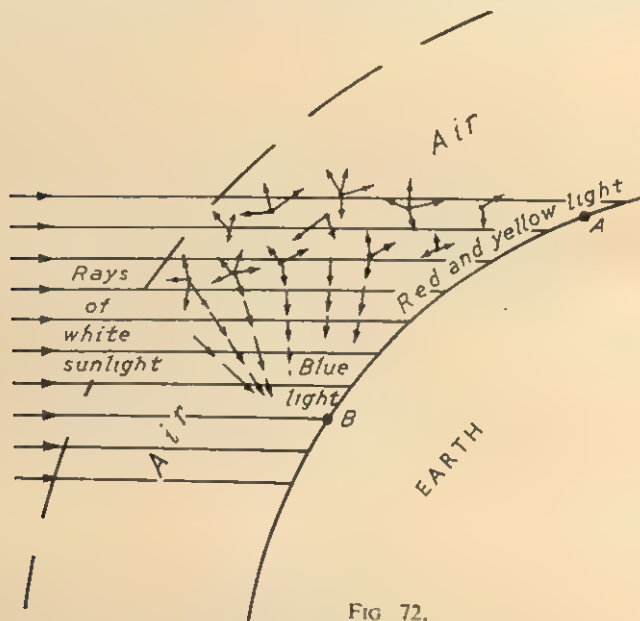

FIG 72.

Consider a man who is standing at A. The rays from the sun reach him at quite a low angle. He sees the sun low in the sky; it is near sunrise or sunset. The rays have to pass through a great thickness of air to reach him, and, during the last few miles, travel near the dusty ground. The particles scatter so much blue light that only red and yellow rays reach him. The sky looks red and yellow. Now consider a man who is standing at B. He sees the sun higher in the sky; it is the middle of the day. The rays from the sun do not pass through so great a thickness

of air and dust. *Some* of the blue light is scattered but, much more important, he receives blue light which is scattered by particles further away (see the drawing). He receives so much blue light in this way that the sky all round him seems blue.

As red light is scattered least by small particles, it reaches further through mist and fog than light of other colours. For this reason, red lamps are often used to show airmen the positions of buildings on an aeroplane field. It is difficult to drive a car in a mist or fog. So much of the blue (and violet) part of the light from the lamps is scattered back to the driver that the mist or fog looks like a thick blue-grey screen. Orange " fog-lamps " are sometimes used (red lamps cannot be used as they are kept for showing the back of a car) but if the fog is thick even the orange light does not reach very far.

Chapter XII

RAYS WHICH WE CANNOT SEE

We know that almost every source of light is also a source of heat (page 8). We can feel the warmth of the sunshine on our bodies; a candle flame is hot. In the year 1800 a scientist tried to find out which colour in sunlight had the strongest heating power. He formed a large spectrum of sunlight on the white top of his table, and held a thermometer in different parts of it. When he held the thermometer in the violet part of the spectrum, it became warm very slowly. The violet rays in sunlight, therefore, have little heating power. As he moved the thermometer gradually towards the red end of the spectrum, he found that the heating effect increased. He did not stop, however, when he had moved the thermometer to the red end. He moved it past the red end into the space where there was no light. He found a very strong heating effect there. Rays came to this part of his table, in front of the red light of the spectrum, but they were rays *which he could not see*. These rays had the strongest heating power. Sunlight, therefore, contains light rays *and* rays which we cannot see. We call the invisible rays which come before the red rays in the spectrum " infra-red " rays. (*Infra* is a Latin word meaning " below.")

If we heat a piece of iron in a fire for a few minutes and then take it out, we find that it gives out heat but not light. It sends out infra-red rays but no light rays. If we make the iron hotter it begins to shine red. It now sends out infra-red rays and red rays. If we make it

hotter still it *also* sends out orange rays, yellow rays, and so on. The wire or filament of an electric lamp sends out infra-red rays and rays of all the colours of the spectrum. The blue and violet rays, however, are not strong. If we make an object so hot that it sends out infra-red rays and rays of all the colours of the spectrum strongly, it shines white. We say that it is " white-hot."

Although infra-red rays are invisible, they are like light rays in several ways. They can be reflected, for example, by pieces of shiny metal according to the well-known law of reflection. They can pass through glass only fairly well but more easily through a substance called " quartz." When they pass into, or out of, glass and quartz they are refracted.

Infra-red rays are important because they are the rays which bring heat from the sun to us. Scientists, however, have found another use for them. By their use, photographs can be taken through mists. Let us see how this is done.
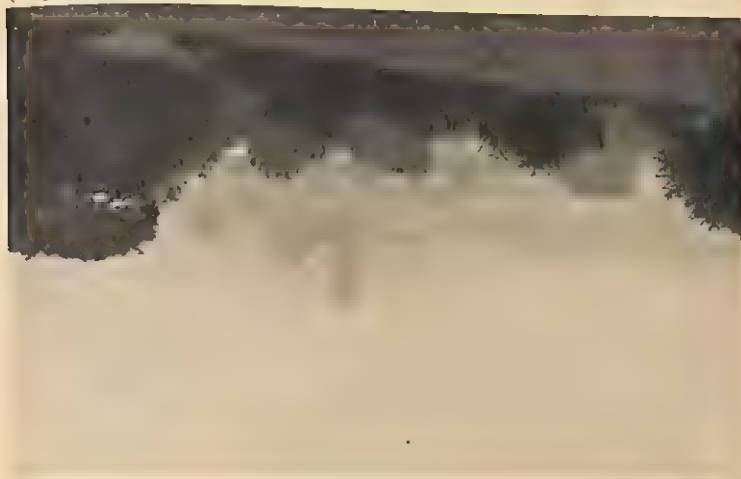
Mist consists of thousands of tiny drops of water floating about in the air. These drops scatter blue and violet rays easily, and although red rays are scattered less, even they cannot pass through a thick mist. We cannot see through a mist, or take ordinary photographs through it, because light does not pass through it. But infra-red rays are scattered less than red rays and can pass through a mist if it is not very thick. Now sunlight contains infra-red rays. Just as objects reflect some (or all) of the coloured rays to the eye, so too they may reflect infra-red rays. These reflected infra-red rays may travel through a mist which is thick enough to stop ordinary light rays.

We cannot see by the infra-red rays which travel through the mist, but we can use them to make a photograph. Infra-red rays have no effect on an ordinary film, but a
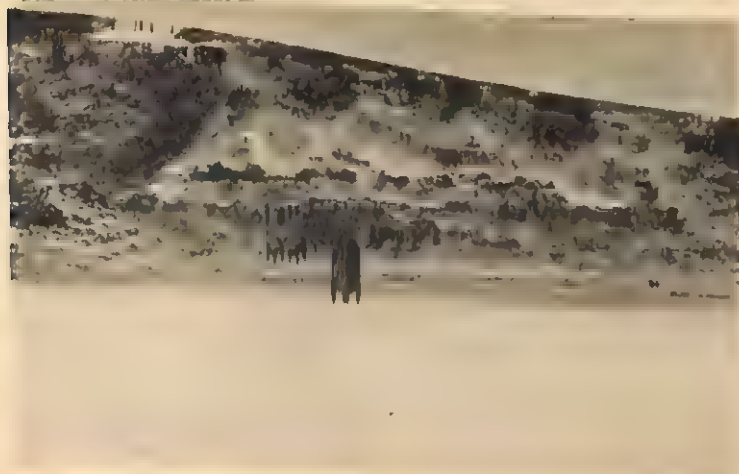
special film can be made by mixing a certain substance with the silver bromide. When taking an infra-red photograph on this special film it is necessary to put a piece of coloured glass (usually red) in front of the camera to stop the blue light, which is scattered in all directions by mist, from coming in.

Infra-red photographs are very surprising. Opposite there is an ordinary photograph taken, in England, on a misty day. Below it there is an infra-red photograph taken at the same place on the same day. The camera "sees" "through the mist! Grass and green leaves always seem nearly white in an infra-red photograph because they reflect the infra-red rays of sunlight well. A blue sky always seems nearly black because, as we have noted, the coloured glass in front of the camera stops blue rays from coming in. On clear days, when there is no mist, infra-red photographs can be taken over great distances. Photographs have been taken in England of the cliffs of France, 22 miles away across the sea. A most surprising photograph has been taken by a man in an aeroplane over America. It shows many valleys and mountains including one 331 miles away!

Within a year of the discovery that sunlight contains rays which come before the red in a spectrum, another scientist discovered that it also contains rays which come after the violet. These rays are called "ultra-violet" rays. (*Ultra* is a Latin word meaning "beyond.") Again, these are rays which we cannot see. Suppose we take a photograph of the spectrum of sunlight, using an ordinary film. The infra-red and red rays have no effect on the film. Most of the light, especially the blue and violet rays, causes the silver bromide to turn black. The film also turns black where the ultra-violet rays fall on it. The ultra-violet rays were discovered in this way.

An infra-red photograph showing the River Thames from London to the sea. The distance from A to B is about 50 miles.

(*The Times.*)

We sometimes say that " fresh air and sunshine " keep people well. It is the ultra-violet rays in sunlight which help to keep us healthy. The ultra-violet rays do not travel through ordinary glass, and the sunlight which comes through a glass window lacks these useful rays. There is a special kind of glass through which the rays can pass more easily. Windows in hospitals are sometimes made of this glass.

A special lamp, which sends out much ultra-violet " light," has been invented. It depends upon the flow of electricity through a gas (page 22). The tube contains a little mercury (or quicksilver). This is usually a liquid. When, however, the current begins to flow, the mercury changes into a gas. The tube then shines with a bright light and also makes a strong beam of ultra-violet rays. If the tube is put inside a vessel made of a special kind of *black* glass, the glass stops the ordinary light but lets the ultra-violet rays come through. The lamp is then a source of ultra-violet rays only.

We cannot see ultra-violet rays. If we shine ultra-violet rays (and no light rays) on an ordinary object, we cannot see the object. There are some substances, however, which *take in* ultra-violet rays and *make* light which we can see. Such a substance, for example, may take in ultra-violet rays and send out blue light. It would seem blue when placed near an ultra-violet lamp. This strange power of certain substances to shine with different colours when ultra-violet rays fall on them has been put to many uses.

If you were shown a box full of eggs, could you pick out the fresh ones from the old ones ? You would have no difficulty if you had an ultra-violet lamp. In ultra-violet rays, the fresh eggs would shine pink, older ones purple, and very old ones blue ! In much the same way you
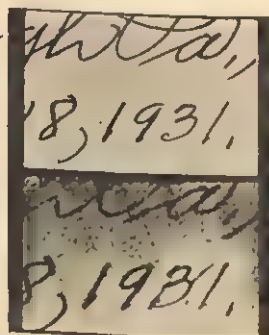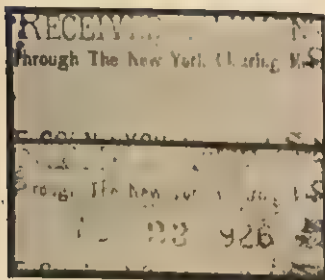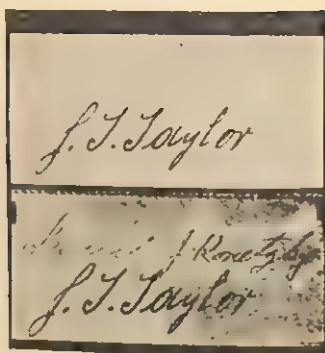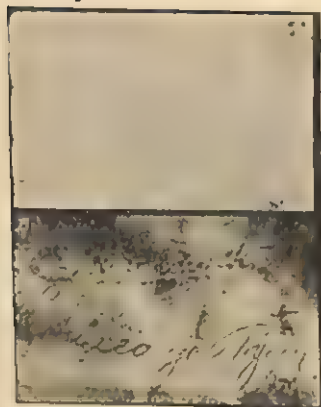
(By courtesy of Eastman Kodak Company and of Hanovia Ltd.)

Use of Ultra-Violet Rays to show that alterations have been made to written letters. In each pair of photographs, the upper one shows the appearance in ordinary light, the lower one in ultra-violet light. Notice that the lower photographs show writing which had been rubbed out.

could tell if some butter has other kinds of fat mixed with it. You could tell if certain jewels were real or if they were useless copies.

The police use ultra-violet rays in finding out certain kinds of crime. Here are some examples. In many countries, paper "notes" are used for money. A criminal thinks, perhaps, he will print some for himself! With difficulty, he gets the right kind of paper and prints correctly on it with ink of the right colour. Unfortunately (for him), the ink may be the right colour in ordinary light, but, unless he uses exactly the right *kind* of ink, it shines with the wrong colour when held in ultra-violet rays. The police can therefore quickly find out what the criminal has done. A man who prints his own postage stamps could be found out in the same way. Perhaps a criminal adds something extra, in ink, on an important written letter, or rubs out some of the writing. If the paper is held in ultra-violet rays, it is almost certain that the change which he has made will show. The pictures opposite are good examples of this.

Infra-red rays, and ultra-violet rays, we have learned, form part of sunlight. There is a third kind of ray which we cannot see. Sunlight does not contain this kind; it is made by a special source.

An electric current can flow through a glass tube from which most of the air has been pumped. It was just over 50 years ago that scientists were studying experiments of this kind. In some of the experiments so much air was pumped out that less than one hundred-thousandth of the air in the tube at first was left. Fig. 73 shows the apparatus which was used. T is the pipe through which the air was pumped out; A and C are pieces of metal fixed inside the tube. When A and C were joined to a strong source of electricity, a small current flowed
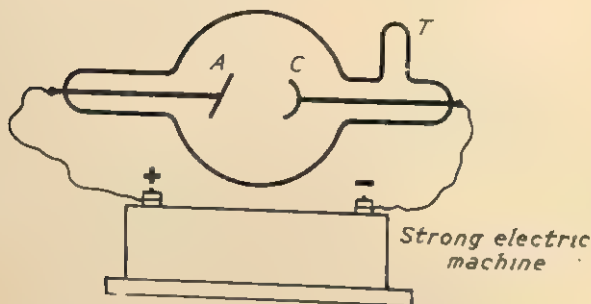
Earth

FIG. 73.

through the tube. The inside of the glass shone with a dim green light.

One of the scientists who was studying this experiment was called Röntgen. It was in 1895. Lying near his apparatus one day there was a piece of paper on which was a certain substance. (Its name is barium platino-cyanide. You need not remember the name but, as you will see, it is an important substance.) He noticed that when the experiment was working, this substance shone with a fairly bright yellow-green colour. Remembering that ultra-violet rays make certain substances shine, he guessed that rays of some kind came out of his apparatus. This, he found, was true. He also found that these rays had a certain strange power. He held a piece of black paper between the apparatus and paper covered with the special substance. The substance still shone. The rays could pass through black paper! In the same way he found that the rays could go through a thin piece of aluminium. Soon it was found that the rays would cause a photo-graphic plate (or film) to turn black, even, of course, when the plate was wrapped up in black paper. Röntgen called

these strange rays " X-rays " because he did not know what they were. Although scientists know more about them now, we still call them by this name.

It was soon found that these X-rays could pass easily through substances such as wood, cloth, and flesh, but could not pass through heavier substances such as iron, lead and bones. Suppose you held, your hand between an X-ray apparatus and a screen covered with the special substance (barium platino-cyanide). The X-rays pass between your fingers and *through the flesh*, and cause the screen to shine.
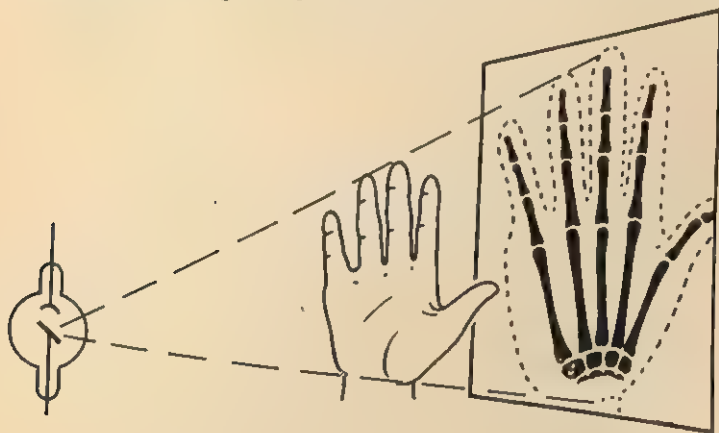

FIG. 74.

They do not pass through the bones in your hand. On the screen, therefore, you see a kind of shadow—the shadow of the bones (Fig. 74). By means of X-rays and the screen you can " see " the bones in your hand ! If, instead of the screen, a photographic film is used, a photograph of the bones can be taken. (Notice that no camera is used ; the X-ray " shadow " takes the place of the image formed by a camera lens.) Within a year or two
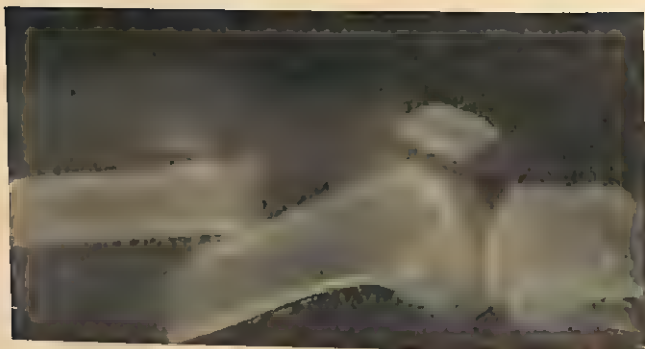
(By courtesy of Ilford Ltd.)

An X-ray photograph showing a leg bone broken just above the knee.
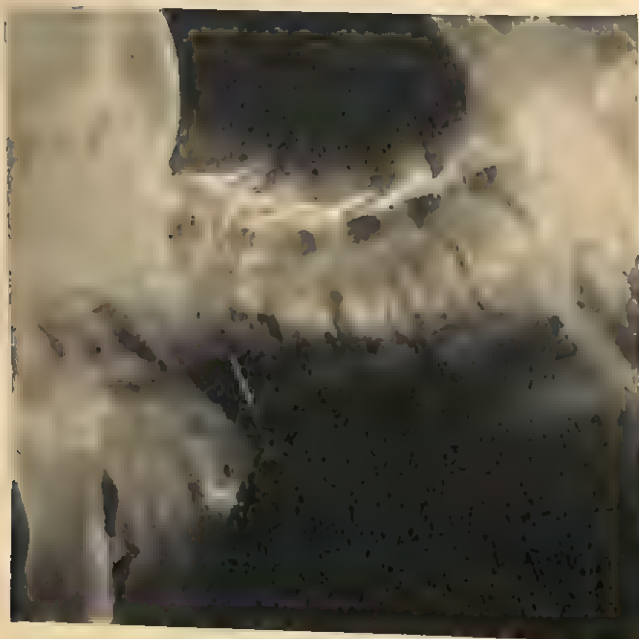
By means of this X-ray photograph, a pin which had been swallowed is seen to be stuck near the top of the throat.

of Röntgen's discovery, a doctor took a photograph of all the bones inside a man's body.

In Röntgen's apparatus the X-rays came from all over the glass tube and could not be controlled. In the better kinds of X-ray tubes which have been invented since, the rays come, in a fairly narrow beam, from a piece of metal like A in Fig. 73. It is easier, therefore, to make them travel in the direction which is wished. Further, we can now make rays of different powers. Thus rays can be made which cannot pass through bones, others can be made which will pass through several inches of steel.

As, by the use of X-rays, a doctor can " see " the bones in a man's body (with the help of the special screen), or take a photograph of them, Röntgen's discovery greatly helps the work of doctors in hospitals. A man, perhaps, breaks his arm. The doctor can " see " just where it is broken, how badly it is broken, and, after he has mended it, if it is healing properly. A baby, perhaps, swallows a coin. An X-ray photograph shows just where it is and the doctor can then decide the best way of getting it out. Another man, we will suppose, has been shot in the leg. The bullet is somewhere in the flesh. Quickly the doctor can find out where it is. These are a few of the many ways in which X-rays help doctors.

An X-ray photograph, as we have noted, is really a kind of shadow. In order that the shadow may be clear, the film is placed close to the person's body. The person need not take off his clothes ; the X-rays go through them ! He does not see the rays, he does not feel them. He must not move while the photograph is being taken, but this may take only half a second.

The stronger X-rays which can pass through metals have other important uses. The metal parts of some machines are made by a process called " casting." You

(By courtesy of Ilford Ltd.)

An X-ray photograph of a steel casting showing cracks which formed inside the metal as it cooled.

know how we sometimes make cement blocks by pouring soft cement into a box and leaving it to become hard. In the same kind of way, some machine parts are " cast " by heating iron until it melts and then pouring it into a hollow form of the required shape. The iron cools and becomes hard. In this process small bubbles and cracks may form *inside* the metal. We cannot see them but, of course, they would make the machine part weak. These faults, however, will show on the special screen, or in a photograph, if strong X-rays are used. In the same way we can discover faults in the joining of metal sheets to make railway engines and ships. We can even " look at " the iron rods which are often placed *inside* the cement from which big buildings are made. By using X-rays of the right strength we can " see " cracks, holes or knots inside wood. The wooden parts of aeroplanes are examined in this way.

The cracks and faults in the metal and wood often form while the object is being made. The great use of X-rays is in finding faults in things *after they are made.* This is true of castings, of aeroplanes—and people !

THE ELECTRIC EYE

A few years ago I was in a certain building in London. I walked towards a door of a room. When I was a few yards from the door it opened. I walked through. The door closed behind me. Now I did not touch the door, and I am quite sure that no one else touched the door. How did this door work?

In my newspaper this morning there is a picture. It shows a famous man stepping out of an aeroplane which had just arrived in America. This may not seem very wonderful. But wait! The man arrived yesterday, the picture is in my newspaper this morning. How was the picture in my newspaper made so quickly?

Our story really begins in 1887. A scientist called Hertz was trying an experiment in which he made a little electric spark jump from the end of one wire to that of another which was near it. He noticed that the spark could jump across a slightly bigger gap if light from another part of the apparatus shone on the wires. This was a very small thing to notice. In fact, many people would not have noticed it at all. Yet some great inventions, two of which we have mentioned, depend upon this discovery.

When light shone on the wires electricity could jump more easily through the short length of air between the ends of the wires. Hertz proved that it was the ultra-violet rays in the light which caused this effect, but he did not study the problem further. A year or two later, two

other scientists found that if one of several rather un-
common metals [1] were used, ordinary light would enable
electricity to pass across a gap from the metal to another
wire. They invented a piece of apparatus which de-
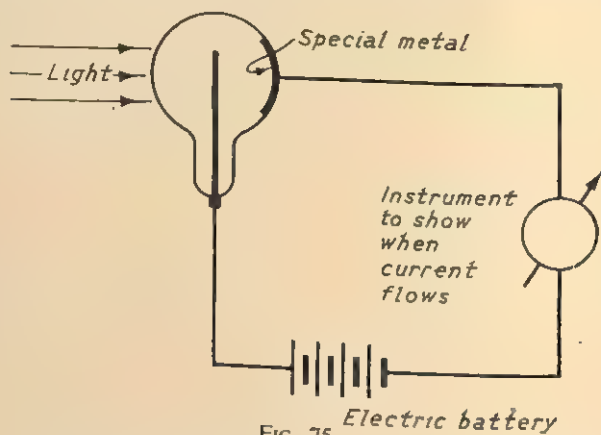pended on this fact and saw some of its uses.

FIG. 75.

Fig. 75 is a simple drawing of the apparatus which they
invented. Part of the inside of a round glass vessel is
covered with the metal; in the middle of the vessel there
is a wire. Most of the air is pumped out of the vessel
because air spoils the bright surface of the metal. The
wire is joined to one end of a strong electric battery. The
metal is joined to an instrument which shows when a
current is flowing, and this is joined to the other end of
the battery. As is usual in drawings of electrical apparatus,
we have used the well-known signs for the battery and the
current-instrument.

If the apparatus is in the dark, no current flows. (The
battery is not strong enough to make electricity jump

[1] These are the " alkali " metals such as sodium and potassium.

across the gap between the metal and the wire.) Now suppose a beam of light shines on the metal. Electricity can pass across the gap; the instrument shows that a current is flowing. We could, if we wish, put the vessel with the metal in one room and the instrument in another room, joined, of course, by the wires. We could then look at the instrument and tell if light is shining in the other room. The arrangement would be something like that of an eye and the brain (Fig. 36, page 63). We can call our vessel with its metal and wire an " electric eye." Its proper name is a " photo-electric cell." (The Greek word *photos* means " light," a *photo*graph is a drawing made by light.)

To-day we use photo-electric cells in which a current flows if quite dim light, or even infra-red rays, shine on them. There are several kinds; one kind is shown in Fig. 76. The light falls on a piece of silver which has been covered by an unusual metal called caesium. The silver " plate " is joined by a wire to a screw at the top. The wire in the middle is bent to a square shape as shown, and is joined to one of the " pins " at the bottom.[1] Usually the air is pumped out of the cell, but in cells for certain purposes a little gas of another kind is put back in its place.

The electric current which flows through the cell when light shines on the metal plate is not very strong. It can be strengthened, or " amplified ", by the use of further electrical apparatus. In the various uses of photo-electric cells which we shall now describe the current must be amplified.

Let us start with the " magic " door which opens when someone walks towards it. Machinery, of course, opens

[1] Some cells, like that in the drawing, have 4 pins so that they can be fitted into special holders.
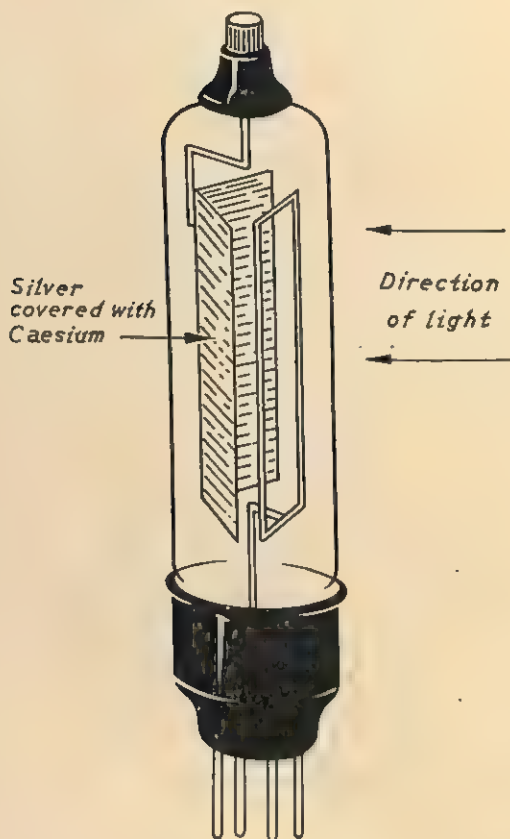
Silver covered with Caesium

Direction of light

FIG. 76.

the door. Somewhere in the room, near the door, there is a lamp which sends a beam of light on to a photo-electric cell. The lamp and cell are arranged so that a man who walks towards the door must pass through the beam (Fig. 77). The cell is joined to the machinery which opens the door, and the machinery is made so that it

cannot work while a current flows through the cell. If the
beam reaches the cell, the current flows, and the machine
does not work. When a man walks into the beam, the
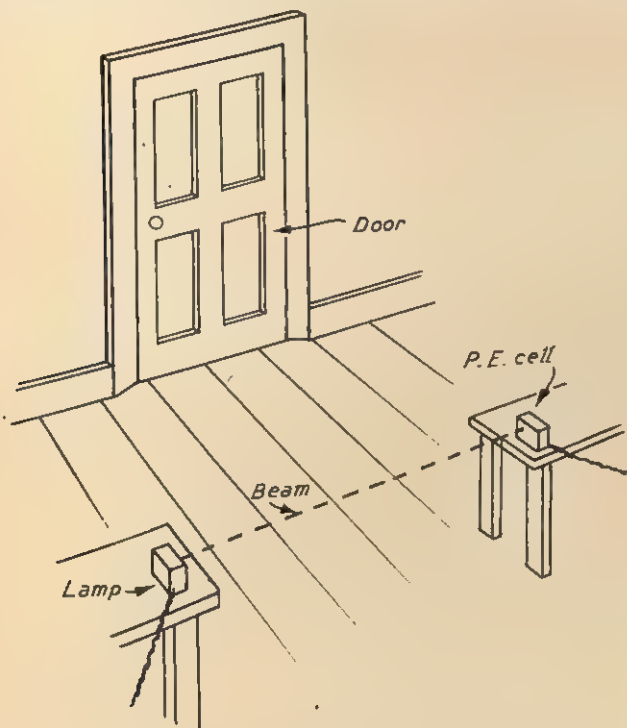light does not reach the cell, the current stops, and the

FIG. 77.

machinery begins to work. The machinery is made so
that it holds the door open long enough for a person to
walk through. Doors which work like this are very useful
in buildings such as factories when people are carrying
parcels and cannot use their hands.

The photo-electric cell, we see, can *control* a machine. Sometimes the cell starts a machine when light falls on it, but more often the cell starts a machine when the light stops falling on it.   This idea is used in many ways.

Suppose, for example, that money and jewels are kept in a cupboard (or " safe ") at a bank.   Near the cupboard there is a beam of *infra-red* rays which shine on a photo-electric cell, and the cell controls a machine which rings an electric bell.   The bell does not ring if the beam reaches the cell.   Perhaps, in the night, a thief tries to steal the jewels.   He cannot see the beam of infra-red rays and so, without his knowing, he walks into it.   The rays no longer reach the cell, the bell rings, and the police who hear the bell know that a thief is there.   A similar idea is sometimes used in buildings where big parcels are stored. The chief danger is fire.   If the parcels catch alight, the smoke stops the rays from reaching the cell, and the machinery rings a bell or even turns on a shower of water to put the fire out.

Fig. 78 shows another use of a photo-electric cell.   A long moving " belt " is carrying parcels into a box.   A beam of light shines across the belt on to a photo-electric cell, and the cell is joined to a machine which shows how many times the current stops.   The current stops every time a parcel passes through the beam, and so the machine counts how many parcels are put into the box.   A similar idea can be used to count how many people go into a building.   In factories photo-electric cells can be fixed near dangerous machinery and arranged so that the machinery stops working if a person goes too close. Photo-electric cells can be used to show accurately the time taken by a man or a car during a race.

We have learned, so far, that an electric current flows through a photo-electric cell when light falls on the metal

in the cell. Now the *strength* of the current depends upon the *brightness* of the light. If the light is bright, the current is strong; if the light is dim, the current is weak. The change in the strength of the current according to the brightness of the light is used in some important ways.
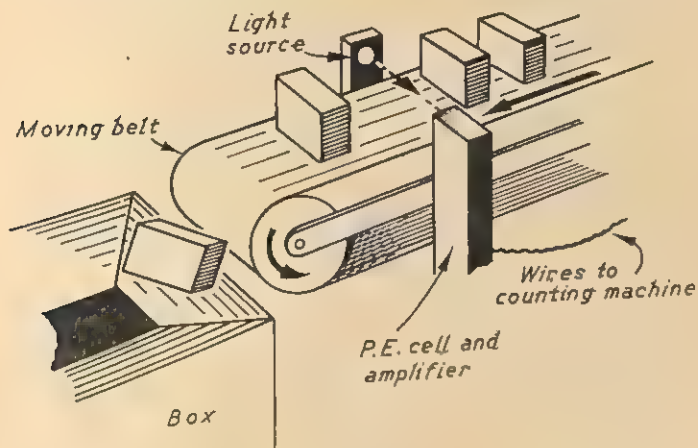

FIG. 78.

First let us see how a picture can be represented by very small squares. Fig. 79a is a simple black-and-white picture of a tree. Fig. 79b is a similar picture, but it consists of rows of black squares. It does not seem to be a very good copy of the first picture when you hold the book near you. Stand the book up 10–12 feet away from you. Now Fig. 79b seems to be a fairly good copy especially if you half-close your eyes. The side of each square in Fig. 79b is $\frac{1}{25}$ of the width of the whole picture. Suppose we had made the squares smaller, for example, $\frac{1}{100}$ of the width of the picture. Then we could have made a copy which seemed quite good even when held fairly near. Any picture in

(a)   (b)

FIG. 79.

black, white and shades of grey can be copied quite well
by making black squares, or dots, but, if the picture is
complicated, the squares or dots must be very small.
Look through a magnifying glass at a picture in a news-
paper, or even at the pictures in this book. They are
actually made of dots ! The printer finds it convenient
to make the pictures in this way, and they are such good
copies of the real photographs that without the magnifying
glass you can scarcely see any difference.

Fig. 80 is a very simple picture. It consists of a large
white square with a black cross in the middle and smaller
grey squares in the corners. We need only to divide this
picture into 25 small squares (as shown by the broken
lines) for each square to be just black, white, or grey. In
row A there is a grey square, then three white squares, and
then another grey square. In row B there are two white
squares, a black square, and then two more white squares,
and so on for the other rows. If we write G for grey,
w for white, and B for black, we can describe the whole

picture, taking it row by row, as GWWWG WWBWW WBBBW WWBWW GWWWG. We could send this description of the picture to a friend. We could write it in a letter, or, more quickly, speak to him through a telephone. Then, if he knows the order in which we have described the squares, he can make his own copy of the picture.
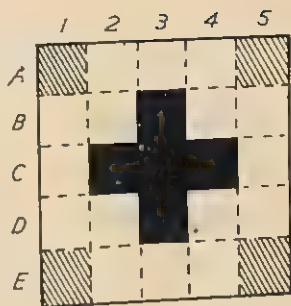

FIG. 80.

Let us improve this idea. Suppose we shine a beam of light on the first square of row A and fix a photo-electric cell near the picture. As this square is grey, a *little* light is reflected to the cell and a *small* current flows. If next we move the picture so that the beam shines on the second square of the row, much light is reflected (because the square is white) and a big current flows. We continue to move the picture, a square at a time, so that the beam shines on each square of row A, then, in order, each square of row B, and so on for the whole of the picture. When the beam falls on a black square, no light is reflected, and no current flows in the cell. The current through the cell changes as we move the picture. If, for short, we write B for big current, s for small current, and N for no current, we can describe all the current changes as SBBBS BBNBB BNNNB BBNBB SBBBS. This changing current can be amplified and sent along wires to the friend many miles away.

The friend can conveniently make a copy of our picture by means of photography. He makes a special lamp shine on a photographic film. The current which we send him controls the lighting of this lamp. If the current is big (representing a white square) a bright beam of light is sent to the film, and so on. When we shine our lamp on

the first square of row A, he shines his lamp on the top left-hand corner of the film. As we move our picture, he moves the film in exactly the same way. If all of this is done perfectly he makes a negative from which he can print his copy.

Although we have described the process for a very simple picture we can see how a more complicated picture, represented by many more squares, could be sent in the same way. The picture is usually fixed to a kind of " drum " which is turned round by a motor. The film is also fixed to a drum and turned round, by a motor, in exactly the same way.

One further improvement can be made. By means of wireless (radio) apparatus the currents which represent the picture can be sent to the distant friend without the use of wires. It was in such a way that the picture in my newspaper was made. We say that the picture was " sent by wireless."

Now we can pass on to one of the greatest scientific inventions of this century. The invention is " television." (Greek word *tele* = far, English word *vision* = seeing.) A man can sit in his home, in front of a kind of wireless set, and see, on a screen, a moving picture of something which is happening *at that very moment*. He can see, for example, a picture of people who are singing and dancing in a building many miles away, or see soldiers marching in the streets of London during a ceremony.

Television works in much the same way as the sending of pictures by wireless. The electric currents, however, do not represent an actual picture, they represent a view (of the dancers, of the London street, etc.), and instead of printing a copy of the picture, the view is shown on the television screen.

We can take a photograph of a view with an ordinary

(By courtesy of Ferranti Ltd.)

A television set showing the picture on the screen.

camera. A " television camera " is used in a similar way but it changes the view into electric currents. The camera lens forms an image of the view on the metal plate of a special kind of photo-electric cell. We can imagine this image or picture to consist of many rows of small squares. Now we know that an electric current flows through the cell when light falls on the metal plate. In this cell, current flows *from each square of the plate in turn.* If the view, and hence the image on the plate, were as simple as Fig. 80, the current flows first from square 1 of row A, then from square 2, and so on for the rest of the row. Then it flows from each square of row B, then from each square of row C, and so on. In actual television, the image may be divided into 180 rows each with 240 squares ! In this way we obtain currents which represent the image on the plate, and hence represent the view.

(B.B.C. Photograph.)

Taking a picture of some dancers with a television camera. The dancers will be seen on the screen of a television set.

In the wireless set which receives the currents there is a special kind of lamp.[1] When the current comes from square 1 of row A, it lights up the top left-hand corner of the screen. When the current comes from square 2 of row A, it lights up the next square of the top row of the screen. This process continues, square by square, row by row, for the whole of the picture. The currents follow each other so quickly that the eye does not notice that the screen is lit up a square at a time. The whole picture is seen all the time.

We must not forget that the things (e.g. the dancers) in front of the television camera are moving, and that we

[1] It is called a cathode ray tube.

wish to see moving pictures on the screen. As we read earlier we must form pictures on a screen at a speed of about 25 a second if we want them to move. So the whole process which we have described is repeated, over and over again, at a speed of 25 a second !

Television is not perfect yet. Scientists are still studying it and improving it. One day, perhaps, television pictures will be as common as electric lamps and motor cars.

And with this great invention we must end our story of the Wonders of Light.

HOW TO MAKE YOUR LIGHT-RAY APPARATUS

IN order to make the light-ray apparatus, for use in experiments described in some of the earlier chapters of the book, you need a source of light, a round glass jar (such as a 1 lb jam jar), and 2 or 3 pieces of card (about the size of a postcard). An electric bicycle lamp is a very suitable source ; a candle, though not so good, can be used. In one card cut a very thin slit or opening, as shown in Fig. 81a, and in another cut two very thin slits about ¼ inch apart, as shown in Fig. 81b. If you
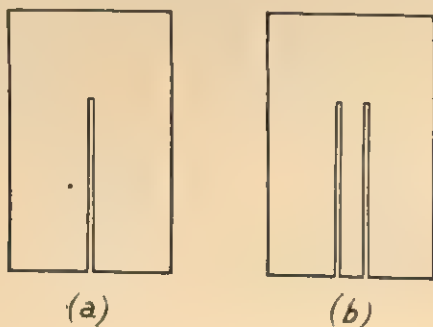

(a)   (b)

FIG. 81.

use a candle you also need a card with one slit nearly $\frac{1}{10}$ inch wide. Arrange to do your experiments on a table in a room which is dark. (Either cover the windows or work at night.)

Using an electric bicycle lamp.

Fill the jar with water and stand it in front of the lamp. Stand the card with one slit against the jar on the opposite

side from the lamp. A thin beam (or ray) comes through the slit. You can " see " it best if you place a piece of white paper on the table. You can get two parallel rays by using the " two-slit " card in the same way. It may be necessary to move the lamp slightly near to, or away from, the jar to make the rays parallel. To get two rays which cross and then spread out, stand the " two-slit " card against the jar on the same side as the lamp, and move the lamp a little further back.

You *may* find it better to take out the reflector of the lamp, but this is not always necessary.

Using a candle.

Place the lighted candle 9–12 inches from the jar of water and stand the " one-slit " card against the jar on the same side as the candle (Fig. 82). If the " two-slit " card is put in place of the " one-slit " card, you get two rays which cross and spread out. It is not so easy to get two parallel rays. The best way that I have found is to put the candle, with the rather wider " one-slit " card immediately in front of it, about 3 inches from the jar. The " two-slit " card is stood against the jar.
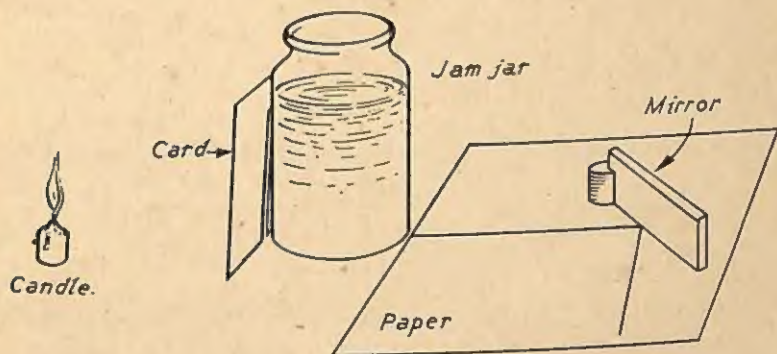

FIG. 82.

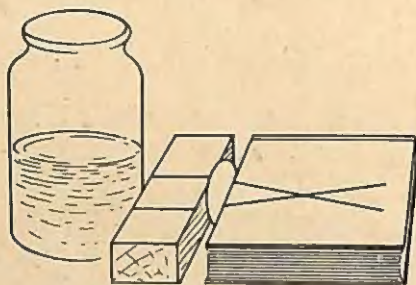You can try it in front of, and behind, the jar, and find which gives you the best rays.
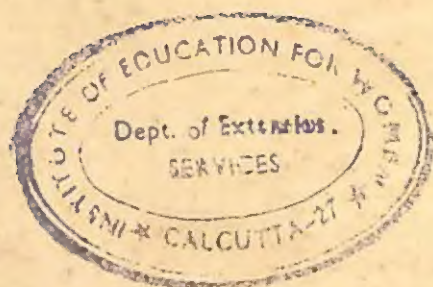

FIG. 83.

Fig. 83 shows how to stand up a lens between books or pieces of wood.

SCIENCE IN
THE MODERN WORLD

THE WONDERS OF LIGHT

This book proceeds from simple ideas to lamps, shadows, and straight-line propagation. Mirrors, lenses and optical instruments such as the microscope, telescope, camera and projector are discussed; and colour, x-rays and the photo-electric cell are also examined.

OTHER BOOKS IN THE SERIES

The Air Around Us deals with wind, rain and weather; breathing; burning; gases; pumps; balloons and aeroplanes.

The Earth On Which We Live deals with the size and shape of the earth; the seasons; maps; the soil and the seas.

Machines and Engines explains simple mechanical contrivances and engines, natural sources of power, electricity and atomic power.

Treasures from the Earth describes mining and the processes of making useful materials from the products, and explains some of the simple chemistry of the processes.

Electricity and Its Uses discusses the essential principles of electric cells and circuits, electric lighting and heating, electroplating and electromagnets.